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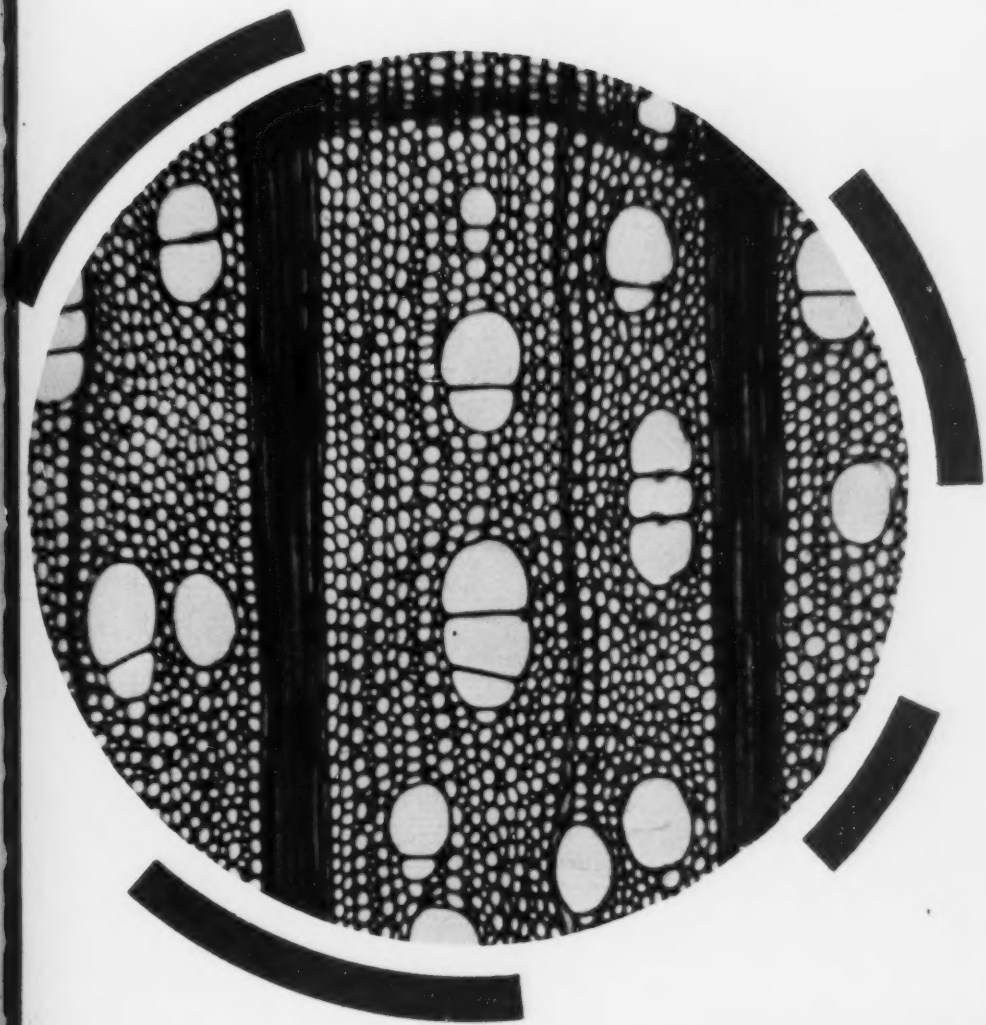

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The cover design is a microphotograph of sugar maple in transverse section by Stephen B. Preston and John F. Kraus, University of Michigan.

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Site Index Studies of Upland Oaks in the Northern Appalachians

BY
G. R. TRIMBLE, JR.
SIDNEY WEITZMAN

SCIENTIFIC FORESTRY, no less than scientific farming, must be based on a knowledge of the productive potential of the land. A standard measure of timberland productivity is site index. For each site index, mensurationists have spelled out, in yield tables, the expected production per acre. Though volumes given in yield tables are averages and may vary considerably from reality, they do show relative differences in growth potential for different sites. They provide a good means of estimating relative yield from areas under management—once the site indexes are known.

A big disadvantage in the conventional use of site index curves for measuring productivity is that site index can be determined accurately only from trees growing in reasonably well stocked even-aged stands. The height growth of open-grown trees or trees growing under conditions of suppression may reflect the influence of spacing and shade rather than basic site productivity. In addition, the stands should be old enough to reflect the full impact of the site factors.

Many—probably most—of our forest stands fail to meet these conditions. Understocked stands, cut-over areas, restocking pastures and old fields, areas of very young timber—all represent unsatisfactory conditions for the conventional height-over-age determination of site index. For this reason, other ways to determine the productivity of forest lands are needed.

In 1953 work was begun at the Mountain State Research Center to devise other methods of determining site index for the principal timber species on the area served by the Center; that is, West Virginia, western Maryland, and southwestern Pennsylvania. The oaks were studied first because they comprise about half of the timber resource in this territory.

Some Earlier Studies

In past studies, attempts have been made to relate physiographic features and soil characteristics to site index. Coile in 1952 summarized in detail the work that had been done in the United States in relating factors of soil and topography to site index. Apparently growth rates of trees are closely related to the amount of available soil moisture. Most soils work done in connection with tree-growth studies has shown significant relationships between tree growth and the physical soil factors that affect water movement and storage. Relating growth to nutrient levels, as is done successfully on cropland, has shown little promise except under conditions of excessive soil depletion on limited areas.

Some investigators have studied the relationship of minor vegetation to forest

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land capability. No widely successful method employing this approach alone has been developed for the United States.

In work with white oak, Gaiser (1951) found aspect and distance from the ridge line to be effective in determining the site index in southeastern Ohio. Site index of white oak increased with distance from the ridge line, and it was higher on northern and eastern aspects than on southern and western aspects. Since he was dealing only with deep soils, total soil depth was not a variable. The depth of the *A* horizon was found to be directly correlated with site index. No significant relationship was found between site index and grade or slope percent of the land.

Einspahr and McComb (1951), working in northeastern Iowa, found that site index of oak increased with an increase in total soil depth. Site-index values were found to decrease as the percent of slope increased. North and east aspects were found to have higher site-index values than south and west aspects. The authors state, in reference to the effect of slope position on site index:

> Differences in site index between lower and middle slopes were significant but not between the middle and upper slopes. An inspection of the basic data for plots otherwise alike showed that the lower slopes generally had thicker soil and that soil depth and topo position tended to be confounded.

They also found that coarse (or light) soils gave lower indexes than heavier soils.

Gysel and Arend (1952), working in Michigan, found that the clay content of the soil is directly related to oak yields. They found that site index is higher on north and east slopes than on south and west slopes, and higher on lower slopes than on upper slopes. They found little effect of grade, but most of the slopes they sampled were less than 20 percent.

Lunt (1939), working with oak sites in Connecticut, found no correlation between measured soil and topographic variables and site index strong enough to form the basis for estimating site index. His findings in regard to site index are summarized as follows:

> There was a low but significantly positive correlation between site index and total nitrogen content of the surface soil. Soil series showed no correlation with site index. With respect to humus types, plots having a mull condition averaged the highest site index, and the fibrous-mor-over-podzol type, the lowest. Topographically there was little correlation other than the obvious one, that plots at the foot of a slope have an average site index considerably greater than those on hill tops. Level, well drained areas were slightly superior to level, poorly drained areas. Site index was inversely correlated with the presence of Vaccinium and Gaylussacia, the mosses, and to a certain extent, witch-hazel; but there was evidence of a direct correlation with the presence of Rubus.

Area Studied

The study area was limited to Tucker, northern Randolph, and southern Preston Counties of West Virginia, and adjacent Garrett County, Maryland. Perhaps three-fourths of the land in this area is forested; a large part is in National Forest.

Topography and climate. This is rough mountain country with narrow valleys and steep slopes. Many of the ridge tops are broad and flat. The larger valleys and broader ridge tops are usually cleared. Most of the slopes are in timber. The average slope percent of the forest land probably falls between 25 and 50 percent. Steep slopes of 75 percent are not uncommon.

Rainfall over the area averages about 50 inches. The steep topography and rapid changes in elevation make for large differences in the amount of precipitation over short distances. However, except for the high points above 3,600 feet, which include little oak forest, the range in average annual precipitation is between 45 and 55 inches. About 6 inches of this falls as snow.

The length of the average frost-free growing season is approximately 140 days. The mean annual temperature is approximately 50° F.

Soils and parent material. Most of the soils of this area are medium in texture, ranging from a very fine sandy loam to a silty clay loam. Their average depth is about 2½ feet. Very few soils are deeper than 5 feet. The DeKalb soils are the characteristic soils of the forest areas. Most are well drained. Water tables are rarely found in the soil mantle.

Sandstone and shale are the parent materials for most of the soils. There is some limestone; it underlies only a small part of the area — perhaps less than 5 percent. This study was limited to areas underlain by sandstone and shale.[1]

Forest cover. Except for small remnants of the old spruce forests at high elevations, the timbered areas are mostly hardwoods. The oaks predominate on the dry sites, and chestnut oak occupies the driest. Red oak is most numerous on the area as a whole and is found over a wider range of sites than the other oaks.

On the moister north and east slopes and in the coves, such species as sugar maple, black cherry, beech, and yellow-poplar are strong components of the stand. Individual red oaks are found in mixture on such areas but stands containing as much as 30 percent oak are uncommon.

Between 40 and 50 years ago a large part of the area was heavily cut over for the first time. On private land, much of this same area has since been recut for mine timbers and other small products.

Study Methods

From the beginning it appeared that a relatively large number of plots would be required to establish the relationship between site index and basic land factors. To prevent confounding this relationship with climatic factors, a study area was selected that was reasonably uniform in rainfall and length of growing season. Once the basic relationships are established for this area, fewer samples will suffice to determine differences in the basic relationships for other parts of the territory where climate or other factors differ slightly.

Seventy-one 1/5-acre plots were measured in even-aged, well-stocked stands. Stand ages ranged between 37 and 150 years, but a majority of the stands sampled were between 40 and 50 years old. These plots were located so as to sample all aspects and topographic positions, as well as the most important soil conditions in the area. Fifty-seven plots were taken on medium-texture, well-drained soils that derived from sandstone and shale on sloping land. This physiographic complex is typical of most of the forest area. In addition, four plots were taken on ridgetops; five on imperfectly and poorly drained medium-texture soils; and five on coarse-texture soils.[2]

Sample trees. This study dealt with the five oaks found in the area: northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), scarlet oak (*Q. coccinea* Muenchh.), chestnut oak (*Q. prinus* L.), and black oak (*Q. velutina* Lam.). In this area, red oak is of the greatest commercial importance.

From 5 to 20 dominant and codominant oak sample trees per plot (average: 10) were measured for d.b.h., total height, length of clear bole (to break-up of trunk

[1]No plots were taken on limestone soils. Including them would introduce another major variable. Limestone soils will be the subject of a special study.

[2]A different number of plots was used in the various tables presented. It was not always possible or desirable to measure each of the factors studied on all plots. For example, in table 1, 67 plots are represented. These are the plots where both red oak and another oak species were found together so that comparisons of site index could be made between them. Other tables were based on the number of plots for which applicable data were available.

into crown), and total age. Both multiple and single stems were used as samples after tests showed that the number of stems per clump had no significant effect on the site index of a stem.

Site index was determined for all the oak species found on the plots. Schnur's site-index curves (1937) were used in doing this. Three years were added to the age at d.b.h. to obtain total age. The site index of the plot was obtained by averaging the site index of all sample trees on each plot.

Table 1 shows the average relationship between site indexes of red oak and each of the other oaks. Although only white oak showed a statistically significant difference from red oak, this does not preclude the possibility of significant differences among the others, because the number available for comparison was not large. On the average, site index for white oak was 95 percent of that for red oak. Average site indexes for plots containing white oak were appropriately adjusted.[3]

TABLE 1. Ratio of site indexes to site index of red oak.[1]

Species	Plots (number)	Ratio
White oak	11	0.95
Black oak	10	.97
Chestnut oak	34	.98
Scarlet oak	12	1.03

[1]Site index of red oak taken as 1.0.

Stand composition. On each plot all trees above 5.0 inches d.b.h. were tallied by species, d.b.h., and crown position.

Reproduction and ground cover. On 5 milacres randomly selected on each plot, reproduction was tallied by species and height. Ground cover was tallied separately for shrubby and herbaceous species, by percent of area covered.

Soils data. The following data were obtained for each plot: soil texture, total soil depth, soil-drainage classification, depth of humus, depth of A_1, depth of A_2, humus type, and pH by horizons. Soil technicians of the Soil Conservation Service assisted in the classification of soils. Laboratory testing was used occasionally as a check against field determinations of soil texture.

Topographic Data. The following topographic data were tabulated for each plot: aspect, slope length, grade, elevation, exposure, and position on the slope (percent distance from the ridge line).

Results

Site Index Estimates Based on Topographic and Soil Factors

Plotting of site index over measured variables, followed by regression analysis, showed that four variables have a major influence on site index. These are: (1) aspect or compass direction faced by the plot; (2) position of the plot on the slope, i.e., distance from the ridge line; (3) grade or slope percent of the land; and (4) total soil depth to rock (Fig. 1).

The curves shown in these graphs were derived from data for the 57 plots used in the analysis. First, the plots were sorted into classes by aspect, slope position, slope percent, and soil depth in four independent sortings. Then the relationship between site index and each of the variables was plotted. Thus each one of the four graphs shows the gross relationship of site index to one factor, ignoring the other three. Such gross relations often obscure net effects when all other factors are held constant. For example, in Figure 1, D the plotted field data show a greater site-index increase between 2 and 3 feet of soil depth than between 1 and 2 feet; yet when all other variables are held constant, the increase is much greater between 1 and 2 feet (Table 3).

[3]Adjustments were made by diviidng the site index of each white oak sample tree by the factor 0.95 (see table). Plot site index was computed using the adjusted site-index value for white oak. These adjustments changed average plot site index for only 4 plots and then by only 1 foot, except for one plot, which was changed by 2 feet.

The effects of these four variables in areas of medium-texture, well-drained soils derived from sandstone and shale were determined through a multiple-regression equation, using data from the 57 plots taken on these areas.

It is usually easier to work with multiple-regression analysis if the independent variables are linear with respect to site index. Gaiser (1951) found good correlation by transferring all nonlinear relations to linear relations. A similar approach was used in this study. The independent variables were made linear with respect to site index by expressing:

1. Site index as its logarithm to the base of 10:
   $Y = \log$ site index
2. The aspect as the sine of the azimuth taken clockwise from southeast and adding 1:[4]
   $X_1 =$ sine (azimuth from SE) $+ 1$
3. The slope position as the percent distance from the ridgeline:[5]
   $X_2 =$ percent distance from the ridge line
4. The grade as the percent slope:
   $X_3 =$ percent slope of the plot
5. The total soil depth to bedrock as the reciprocal of soil depth in feet:

$$X_4 = \frac{1}{\text{Soil depth in feet}}$$

The resulting equation is:

$$Y = 1.9702 - 0.0618\ X_1 + 0.0012\ X_2 - 0.0020\ X_3 - 0.1509\ X_4$$

The correlation coefficient of 0.8683 is significant at the 1-percent level. The standard error of estimate is approximately 9 percent at the point of average site index—66 feet.

[4]Starting at the southeast puts the southwest aspect (which has the lowest site index) and northeast aspect (which has the highest site index) into their proper positions. Adding the sine plus 1 eliminated negative numbers.

[5]Slope positions are rated in relation to the over-all distance from ridge to stream or to bottom of the slope.

TABLE 2. Regression and correlation coefficients for the variables in the site-index equation.

Variables	Partial regression coefficients	Total correlation coefficients with Y[1]
Aspect	−0.0618	0.5083
Slope position	+0.0012	0.5299
Grade	−0.0020	0.4038
Soil depth	−0.1509	0.4915

[1]Significant at the 1-percent level.

Table 2 shows the regression and correlation coefficients.[6] The former show the contribution of each variable to log site index.

Two other total correlation coefficients are significant at the 1-percent level: the correlation coefficient between slope position and soil depth is 0.3856, and the correlation coefficient between grade and soil depth is 0.4393. In other words, the greater the distance from the ridge line and the lower the grade, the greater the soil depth.

From the equation, the data in Table 3 were developed. These can be used in the field to estimate oak site indexes from observations of land factors. Briefly, these data show that:

1. North and east slopes have higher site indexes than south and west slopes. All other things being equal, northeast slopes have sites about 1 to 2 site-index classes higher than southwest slopes.[7]
2. Site index increases from ridge line to

[6]The regression coefficients are ordinary partial regression coefficients, being average rates of change in Y (log site index) per unit change in X, other variables being constant. The correlation coefficients are total and show the gross association of the corresponding variables without adjustment for the other Xs.

[7]Site-index values are grouped into 10-foot classes. Site-index class 40 includes all site-index values from 35 to 44; site index 50 includes all site indexes from 45 to 54, etc.

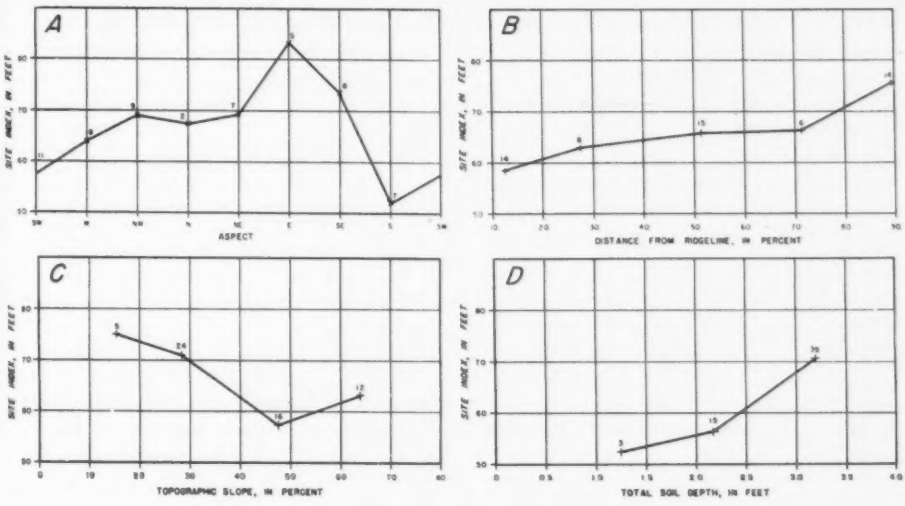

FIGURE 1. *The relation of oak site index to* A, *aspect;* B, *distance from ridge line;* C, *slope percent; and* D, *total soil depth. The numbers on the curves indicate number of plots.*

lower slope. Again, everything else being equal, the oaks on the bottom of the slope will be about 2 site-index classes better than those at the top of the slope.

3. Increasing grade has an adverse effect on site index. Site index decreases 2 to 8 feet with each 20 percent increase in slope of the land.
4. Site index increases with an increase in soil depth. The rate of increase, however, diminishes with increasing soil depth. Increasing the soil depth from 1.0 foot to 2.0 feet at the bottom of a 40-percent slope on a SW aspect increases site index 11 feet. Increasing soil depth from 2.0 feet to 3.0 feet in a similar location increases site index only 3 feet. The effect of soil depth on site index probably levels off somewhere between 3.0 and 4.0 feet.

Table 4, taken from Schnur, shows yield-table volumes for a range of site-index classes. Figures 2, 3, and 4 illustrate different site classes.

SPECIAL SITUATIONS THAT AFFECT SITE INDEX

Though the equation applies to the major land-soil complexes in the area, there are special situations in which it does not apply. These are: ridgetops, areas of impeded soil drainage, light-texture soils, and medium-texture soils from sandstone and shale of the Ashby series. These conditions are discussed individually.

Ridgetops. The site index of oaks on ridgetops is influenced by the width of the ridgetop: the sharper the ridge, the lower the site index. Three plots were taken on flat ridgetops between ½ and 2 chains wide. These indicate that such sites are comparable to a SW slope on a 5-percent grade at the upper-slope position. For soils 1.0 foot deep, site index would be 53; for soils 2.0 feet deep, it would be 63; and so on. Narrower ridges have site indexes comparable to SW slopes on 5-percent grade at the top-of-slope position. Gaiser found a similar relationship for white oak in Ohio.

TABLE 3. Site index of oak as related to aspect, slope, and total soil depth.

Aspect	Soil depth (feet)	Slope percent							
		10	30	50	70	10	30	50	70
		TOP OF SLOPE				UPPER SLOPE			
SW (225°)	0.5	34	31	28	26	37	33	31	28
	1.0	46	43	40	36	52	47	43	39
	2.0	57	52	47	43	62	56	51	47
	3.0	60	55	50	45	65	60	54	50
NW (315°) and SE (135°)	0.5	39	35	32	29	42	39	35	32
	1.0	55	50	46	42	60	55	50	45
	2.0	65	59	54	49	71	65	59	54
	3.0	69	63	57	52	75	69	63	57
NE (45°)	0.5	45	41	37	34	49	44	41	37
	1.0	63	58	53	48	69	63	57	52
	2.0	75	69	63	57	82	74	68	62
	3.0	80	73	66	60	87	79	72	66
		LOWER SLOPE				BOTTOM OF SLOPE			
SW (225°)	0.5	40	37	33	30	44	40	37	33
	1.0	57	52	47	43	62	57	52	47
	2.0	68	62	56	51	74	68	62	56
	3.0	72	65	59	54	78	72	65	60
NW (315°) and SE (135°)	0.5	46	42	39	35	50	46	42	38
	1.0	66	60	55	50	72	66	60	54
	2.0	78	71	65	59	85	78	71	65
	3.0	83	75	69	63	91	83	75	69
NE (45°)	0.5	53	49	44	41	58	53	49	44
	1.0	76	69	63	57	83	76	69	63
	2.0	90	82	75	68	99	90	82	75
	3.0	95	87	79	72	104	95	87	79

Ridges wider than 2 chains are rarely flat, but slope gently; and the normal relationships shown in the tables will hold for them.

Drainage. Most of the forest soils in this area are well drained. However, there are a few areas of impeded drainage on medium to heavy-texture soils on low grades. This condition has an adverse effect on oak site index. Data from five such plots gave significantly lower site indexes than on otherwise similar but well-drained soils. Where oaks are found on poorly drained soils, the site index is reduced about half a site class or 5 feet.

Soil texture. Five plots were taken in the range of light-texture soils (loamy sand to fine sandy loam). Such soils are generally poorer for tree growth than heavier texture soils. While the data were not sufficient to establish the amount of departure from the equation due to increasing soil coarseness, they do indicate that as the soil becomes coarser the site index of oak declines. This trend is in accord with the findings of Gysel and Arend in Michigan.

Ashby series. Though the area occupied by soils of this series is small, this soil type constitutes a special problem. These medium-texture soils produce poor tree growth for

TABLE 4. Yield of upland oaks by site index and age[1]

(In thousand board feet per acre[2])

Site index	Age in years		
	50	75	100
40	1.4	5.1	9.2
50	3.2	9.3	14.7
60	6.3	14.2	20.9
70	9.8	19.5	27.6
80[3]	13.8	25.2	34.4

[1]Adapted from Schnur's (1937) Table 14 and Figure 10.

[2]International rule, ⅛-inch saw kerf. Includes all trees having at least one 16-foot log to a 5-inch top inside bark.

[3]No volumes are available for sites above 80 because the yield tables were developed for stands having 30 percent or more of the dominant stand composed of upland oak species. Above site index 80, oak is only a minor component of the stands.

reasons not as yet determined. Ashby soils are formed on tilted shales (with some sandstone) and are characteristically well or excessively drained and dry soils. Additional sampling will be necessary to establish the amount of departure from the site-index equation developed in this study.

SOME OTHER FACTORS THAT AFFECT SITE INDEX

The following factors probably affect site index also. They were not measured separately as variables, either because they occur infrequently or because their effect is obviously small. These factors account for some of the error of estimate in determining site.

Exposure. Exposure, or the effect of shading by nearby land masses, undoubt-

FIGURE 2. *Example of a very poor oak site (site-index class 40). This is on a west-facing slope near the top of a steep hill; the soil is shallow. Chestnut oak is dominant; notice the short boles and the poor form. This stand is unmerchantable.*

FIGURE 3. *A medium oak site (site-index class 60). This is on moderately sloping land about one-third the distance down from the ridge. Red oak is dominant, and there are some hickory and chestnut oak. Form and height are better here.*

edly affects site index. Auten (1945) noted the effect of this factor in his study of yellow-poplar sites. Though this factor was noted at each plot, the data were not conclusive.

Stone content. Stone content of the soil undoubtedly affects site index under some conditions. On lower slopes, which usually have fairly deep soils, site index appears to be unaffected by a large amount of stone. These areas apparently have enough soil for maximum tree growth. On upper slopes, particularly those of limited soil depth, a high stone content appears to reduce the site index. It is suggested that the equation for site index be reduced by 5 feet on the upper half of slopes where soil depth is less than 3.0 feet and stone content is 50 percent or greater.

Variation in soil depth. Soil depths often vary over small areas. Where this occurs, it is difficult to get an exact average depth for the plot. Thus, the variation in soil depth was a contributing factor to the error of estimate.

FIGURE 4. *Example of a very good oak site (site-index class 80). This is on gently sloping land near the bottom of a hill facing orth. Here red oaks are found in mixture with black cherry, sugar maple, beech, and yellow-poplar. Notice the length of the clear stems as compared to the height of the man in the foreground.*

Density and suppression. All of the site-index plots were in stands that were more or less well-stocked and even-aged at the time the data were taken. Plots where the sample trees showed a definite suppression period were discarded. Plots that apparently had been understocked in early life were not sampled. However, in their lifetime the trees sampled were undoubtedly subjected to varying degrees of density and in cases to some suppression.

Elevation. The plots sampled range in elevation from 1,400 to 3,800 feet but were concentrated between 1,800 and 3,500 feet, where most of the forest land occurs. It is possible that differences in elevation affect the site index since elevation affects precipitation and temperature.

Slope length. Slope lengths from 5 to 120 chains were included in this study, and they were combined in the analysis. The data were insufficient to indicate the effect, if any, of slope length on site index. If this variable affects site index, it also contributes to the error of estimates.

Other Indicators of Site

LENGTH OF CLEAR BOLE

Clear length of tree bole has often been used in the field as a rough guide to site quality. The accuracy of this method was tested on the sample trees. The relationship between clear length and site index is expressed by the equation

$$S.\ I. = 27.6524 + 1.2402\ (\text{clear length})$$

The error of estimate is approximately 27 percent, which is too large for estimating 10-foot site-index classes. It may be used as a rough guide.

All of the oaks except scarlet oak have similar merchantable heights and were included in this equation. Scarlet oak, because of its branching habit (small lower branches that can be considered part of

the clear bole rather than the crown), has a clear length 2 to 3 feet higher than the other oaks.

The effect of age on clear length was tested. The stands sampled ranged in age from 37 years to more than 150 years. For stands in this age group, clear length was unaffected by age. Apparently by age 37 the oaks have established their branching form and their clear length.

HUMUS TYPES

The predominant humus types[8] found in the areas sampled are medium mull and duff mull, but other mulls and mors also occur. In general, as site index increases, the proportion of medium, coarse, and fine mulls increases at the expense of duff mull and mors. This is natural for this region where true mulls are associated with moist sites and the duff mull and mors with dry sites.

DEPTH OF A-HORIZON

Plotting site index over depth of the humus (A_1 or H) shows a relationship between the two. Humus depths increased from 1.8 inches for site index 50 to 4.0 inches for site index 90. No attempt was made to use this depth as a variable in estimating site index because it was considered too susceptible to modification through changes in stand conditions such as cutting. Studies by Sartz and Huttinger (1950) and Trimble (1952) have shown how the depth of the humus depends on stand age and condition; therefore, it is not a reliable indicator of site potential.

Correlation of site index with depth of the total A horizon as was done in Ohio by Gaiser was not attempted in West Virginia. Here the soils are immature and have typical AC profiles. The lower part of the A (the A_2) grades so imperceptibly into the C horizon that precise field measurement is not practical.

[8]As defined by M. D. Hoover and H. A. Lunt in "A key to the classification of forest humus types." Soil Sci. Soc. Amer. Proc. 16 (4): 368-370, 1952.

pH

The data show a very slight general increase in site index with increasing pH. In the A_1 horizon there is an increase from 4.2 for site index 40 to 4.7 for site index 80. In the A_2 horizon pH increases from 4.4 to 4.8 for the same range of site indexes. The C horizon tested rather uniformly at 4.5.

It is doubtful that the relationship in the A horizon is meaningful. The poorer sites are generally stocked with scarlet oak and chestnut oak, whose leaves have a lower pH than the leaves of yellow-poplar and sugar maple, which are found in mixture on the better sites. In any case, the range in pH is so small and the variation within site-index classes is so great that difference in pH cannot be considered to have any practical significance.

GROUND COVER

The existence of a relationship between site index and ground cover was investigated. Though the data show that such a relationship exists, ground cover is not as reliable for estimating site index as land features are, for several reasons. Foremost, of course, ground cover is not a good indicator during the dormant period. It cannot be used in open areas. Even under a forest canopy, ground cover is greatly influenced by light; so the species and the proportion of the forest floor occupied vary greatly with the degree of opening. Also, the species composition and the amount of ground cover change only gradually as site index changes.

The extreme variability in amount and composition of ground cover even in uniform stands makes it impractical to attempt to measure even 10 foot site-index differences. However, it is possible to use ground cover for classifying sites as "poor," "medium," and "good." Thus it offers another useful but not very precise tool for the practicing forester.

From this study, a general ground cover and humus guide to site index is suggested for the following grouping of site indexes:

Poor sites (site indexes 40 and 50); medium sites (site indexes 60 and 70) and good sites (site indexes 80 and above).

Poor sites. Here shrubby ground cover is abundant. It is composed of blueberry (*Vaccinium* sp. L.), greenbrier (*Smilax* sp. (Tourn.) L.), mountain-laurel (*Kalmia latifolia* L.), and wild azalea (*Rhododendron calendulaceum* (Michx.) Torr. and *R. arborescens* (Pursh) Torr.). Herbaceous ground cover is usually sparse and of very few species. It is composed characteristically of teaberry (*Gaultheria procumbens* L.), tick trefoil (*Desmodium* sp. Desv.), goldenrod (*Solidago* sp. L.), and often trailing arbutus (*Epigaea repens* L.). The humus is a patchy duff mull with many spots of bare mineral soil and moss.

Medium sites. Shrubby ground cover is less abundant but is composed of more species. Here greenbrier is the most abundant and blueberry is a minor component. Dewberry (*Rubus* sp. (Tourn.) L.) and blackberry (*Rubus* sp. (Tourn.) L. as well as witch-hazel (*Hamamelis virginiana* L.) are more abundant than on poor sites. Some mountain-laurel is present but rhododendron (*Rhododendron maximum* L.) is competing with it. Herbaceous ground cover is more prominent and is of greater variety than on poor sites. Teaberry is still abundant; but violet (*Viola* sp. (Tourn.) L.), twistedstalk (*Streptopus amplexifolius* (L.) DC.), and wild yam (*Dioscorea villosa* L.) are numerous also.

Good sites. Shrubby cover is less, but the amount of herbaceous vegetation is much greater. Mountain-laurel is rare here but rhododendron (*Rhododendron maximum* L.) is relatively abundant. Nettles (*Laportea canadensis* (L.) (Gaud.), touch-me-not (*Impatiens* sp. (Rivinius) L.), stonecrop (*Sedum ternatum* Michx.), and twistedstalk are key species in the herbaceous layer. The humus is characteristically an unbroken medium mull.

Summary

The productivity of most of the forest land in the northern Appalachians can be estimated from information on (1) aspect of the site; (2) position of the site on the slope, i.e., distance from the ridge line; (3) grade of the slope at the site; and (4) total soil depth to bedrock. Such estimates may be 9 percent in error at the point of average site index—66 feet.

Observations on ground cover — both shrubby and herbaceous—can be used by a trained man to indicate general site conditions. However, this method does not lend itself to precise estimating.

Use of length of clear bole as a measure of site index, like ground cover, is useful only to indicate general site conditions. It is not a reliable tool for mathematical estimating.

Humus type and depth, and pH as well, show some relationship to site index, but these relationships are not close enough for estimating purposes.

Some factors affecting the error of estimate are: exposure or extent of shading, stone content of the soil profile, variation in soil depths over the plots sampled, past history of the stand—especially the degree of suppression and density of stocking—elevation differences, and length of slope.

Literature Cited

Auten, J. T. 1945. Prediction of site index for yellow-poplar from soil and topography. J. For. 43: 662-668.

Coile, T. S. 1952. Soil and the growth of forests. Advances in Agron. 4: 329-398, illus.

Einspahr, Dean, and McComb, A. L. 1951. Site index of oaks in relation to soil and topography in Northeastern Iowa. J. For. 49: 719-723, illus.

Gaiser, R. N. 1951. Relation between topography, soil characteristics, and the site index of white oak in Southeastern Ohio. U. S. Forest Serv. Central States For. Exp. Sta. Tech. Paper 121. 12 pp., illus.

Gysel, Leslie W., and Arend, John L. 1952. Oak sites in southern Michigan: Their classification and evaluation. Mich.

State Coll. Agric. Exp. Sta. and U. S. Forest Serv. Lake States For. Exp. Sta. joint Tech. Bull. 236. 57 pp., illus.

LUNT, HERBERT A. 1939. Soil characteristics, topography, and lesser vegetation in relation to site quality of second growth oak stands in Connecticut. Res. 59: 407-428.

SARTZ, R. S., and HUTTINGER, W. D. 1950. Some factors affecting humus development in the Northeast. J. For. 48: 341-344, illus.

SCHNUR, G. L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. U. S. Dep. Agric. Tech Bull. 560. 88 pp., illus.

TRIMBLE, GEORGE R., JR. 1952. A method of measuring increase in soil depth and water-storage capacity due to forest management. U. S. Forest Serv. Ntheast. For. Exp. Sta., Sta. Paper No. 47. 8 pp.

Contributions to Plant Anatomy

By Irving W. Bailey. Chronica Botanica Co., Waltham, Mass. 259 pp. Illus. 1955. $7.50.

Review by Hugh Wilcox
College of Forestry, State University of New York

Few botanists are better known to students of plant science than Harvard's Irving W. Bailey. Likewise, few botanists have contributed papers in so many diverse areas of botany. It is a signal event that Professsor Bailey has been induced to make a selection of his papers for presentation in book form.

"At the beginning of the century," the author states in his preface, "the older botanical disciplines had become rigidly compartmentalized and concerned with the applications of stereotyped techniques. At present, the fixed boundaries between the scientific disciplines are rapidly breaking down and diversified new techniques are being commonly applied. Thus, the papers in this book have been selected and arranged to illustrate successive attempts between 1909-1953 to bridge the gaps between plant anatomy and other fields of scientific endeavour."

The selected papers are grouped in eight parts, the first seven of which are concerned with the relations of plant anatomy to cytology and ontogeny, biochemistry and biophysics, phylogeny, taxonomy, entomology, paleobotany, and wood technology. The contributions range from the highly abstract to the immensely practical. Here are found his classic papers on the cambium and its derivative tissues and his lucid accounts of the microstructure and physical organization of the plant cell wall. Perhaps less well known to foresters are his studies of the structure of the secondary xylem as a tool in solving problems in the evolution of land plants.

Of particular interest to taxonomists is the section describing the investigations of Professor Bailey and his students on the floral morphology of various families in the Ranalean complex. These papers disclosed much regarding the morphology of the primitive form of the dicotyledonous carpel and its trends of specialization.

The account of his investigations of "ant-plants" introduced the reviewer to a bizarre and intriguing relationship between ants and certain tropical plants. His analysis of the cumulative circumstantial evidence is most ingenious.

The last section of the book consists of selected portions from "The Role of Research in the Development of Forestry in North America," published in 1929 in collaboration with the late H. A. Spoehr. This report was one of the first to present a comprehensive picture of the importance, scope, status, and needs of forestry research. A quarter-century after the publication of these recommendations by Bailey and Spoehr the urgency still exists for large increases in research activity in the sciences basic to forestry. Their words have a compelling cogency if we are to continue to make progress in forestry.

A biographical sketch of Professor Bailey is presented in the early pages of the book. This is followed by a bibliography of his writings from 1909-1953. Especially pleasing are the sectional title pages, headpieces, and vignettes artistically drawn by Dr. B. G. L. Swamy.

Pathological Aspects of Severe Spruce Budworm Attack

BY
M. A. STILLWELL

SEVERE DEFOLIATION of balsam fir, *Abies balsamea* (L.) Mill., by the spruce budworm, *Choristoneura fumiferana* (Clem.), was first noticed in the vicinity of the South-East Upsalquitch River in northern New Brunswick in 1949. Aerial spraying in New Brunswick began in 1952, the fourth year of severe attack. A study by Belyea (1952) of budworm-attacked balsam fir in the Lake Nipigon area of Ontario showed that mortality of balsam fir may be expected in the fifth year of attack. Thus, the 1952 spraying occurred a year before the first mortality would be expected.

For the most part, aerial spraying in New Brunswick was not attempted until timber mortality seemed almost certain. This procedure was followed in order to take the best advantage of natural control and minimize the possibility of unnecessary spraying. The first mortality of suppressed and partly suppressed trees in unsprayed stands occurred in 1954, the fifth year of attack in this particular area (Webb, 1955).

When budworm defoliation causes death, it becomes a simple matter to assess the damage caused by budworm attack in terms of the amount of timber lost. The death of the tree has been observed to progress from the tip downwards, and it is known that epidemics of the budworm sometimes subside after causing various degrees of top killing but after killing only a small number of trees, particularly in younger stands. The same situation occurs in all stands when spraying is delayed until tree mortality is imminent. Dead tops provide an excellent means of entry for wood-destroying fungi. It is possible that the incidence of trunk rot in stands of timber may be greatly increased as a result of heavy but not fatal attack by the spruce budworm. This damage would not be readily apparent as it does not show up for a number of years following outbreaks. It was necessary, therefore, to examine trees injured by budworm in the previous attack of approximately 1912-1920 to assess this form of damage.

A study of growth patterns on several hundred stumps in various cut-over stands in the Green River Watershed indicated severe defoliation over the whole area. This earlier outbreak caused heavy mortality in some stands, while in other stands killing was almost negligible. Both types of stands were predominantly balsam fir at the time of attack. Trees which survived had an average age (at stump height) of about 45 years, while those which suffered heavy mortality had an average age of approximately 75 years at the time of attack

Contribution No. 281 from Forest Biology Division, Science Service, Department of Agriculture, Ottawa. The author is located at Forest Biology Laboratory, Fredericton, New Brunswick.

FIGURE 1. *Diagram to show the appearance of a balsam fir that has had the top killed as a result of spruce budworm defoliation. "A" represents stub of main leader, "B" and "C" dead branch tips.*

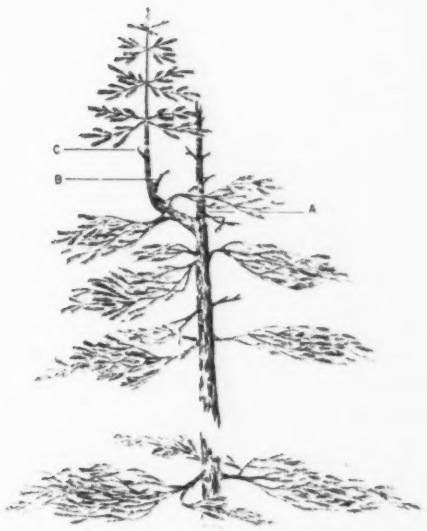

FIGURE 2. *Diagram showing how a new leader arises from an uninjured branch terminal; "B" and "C" are both injured branch terminals, "A" again represents dead stub of killed leader. This illustrates the same tree as in Fig. 1, but four years following the end of defoliation.*

(Morris, 1946). It has been suggested that the younger and more vigorous nature of the stands was responsible for the limited amount of mortality at that time (Morris *et al*, 1955).

Observation of trees in the Green River Watershed of New Brunswick showed that numerous trees had deformities which could have resulted from the previous budworm attack. These deformities could be grouped in three main classes, as follows:

I. Trees with forked tops.
II. Trees with marked crooks, with or without visible dead leaders.
III. Trees with slight sweeps or crooks.

Trees having any one of these deformities were dissected to determine whether decay had entered at these points.

Methods

The trees were cut at a height of one foot, sectioned in four-foot bolts, and scaled up to a three-inch top. For each tree the total age at the stump was determined, and the period of budworm defoliation was dated by counting the annual rings from the beginning and end of the suppression caused by budworm attack out to the cambium. The diameter at breast height and at the level of the injured top was taken. The diameter at stump height inside suppressed rings due to budworm attack was recorded. Decay was measured in both the butt and trunk. Bolts were

repeatedly split to determine the point of entry for the various decays.

Care was taken to ensure that the above deformations resulted from defoliation by budworm. This was done in the following manner: The trees were cut well above and below the deformation and age was taken at each cut. If the deformation resulted from budworm attack, the upper cut would contain approximately 30 annual rings or less and only recent suppression rings would be apparent. The lower cut would contain 40 annual rings or more if the deformation resulted from budworm attack, and consequently a pattern of suppression due to budworm defoliation similar to that at the stump. There was often a difference of a year or two, suppression at the stump generally beginning a year later and lasting a year longer. When it was confirmed that the deformity was due to budworm, the bolt was split and the dead leader exposed. The age and diameter of the dead leader were obtained. The year of death of the injured top was determined by substracting the age of the leader from the total age of the tree immediately below the dead leader and substracting the remainder from 1955.

In the course of the study, five trees were found to be forked as a result of the attack. However, since the main leader was simply suppressed and did not die for several years following budworm defoliation, these trees were not used, as it was necessary to secure trees in each class which had their tops killed either during the budworm attack or within the next two or three years.

The incidence and extent of decay entering dead tops as a result of injuries sustained from the earlier budworm attack were recorded. Data were taken also on decay which originated from sources other than injuries sustained from budworm feeding.

Observations and Results

It soon became apparent that trees with

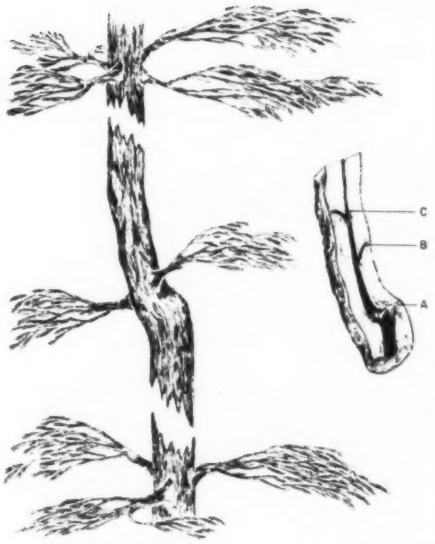

FIGURE 3. *Diagrams to show the appearance of the same tree as illustrated by Figs. 1 and 2 approximately 35 years following the end of defoliation. Insert shows bolt split to reveal buried leader "A" and buried branch tips "B" and "C."*

the tops killed by budworm could have as many as three buried terminals (one leader and two branch tips) or, in the case of forked trees, five buried terminals. This can be more easily explained by referring to Figs. 1, 2, and 3 where "A" represents stub of main leader, "B" and "C" dead tips of a branch from which a new leader will eventually grow. In dominant and codominant trees these stubs, A, B, and C, usually remain exposed for a few years and in time become healed over. Suppressed trees, however, grow more slowly and "A" and sometimes "B" often remain exposed for as long as 35 years or more following the injury (Fig. 6).

The results of the study tend to show that incidence of decay is high in trees that

TABLE 1. Description of trees forked as a result of the 1912-1920 spruce budworm outbreak in northern New Brunswick.

Tree No.	Total age at stump	D.B.H.	Diam. at stump beginning of budworm attack	Total ht. in ft.	Ht. of fork in ft.	Diam. of dead leader in in.	Age of dead leader	Time of death of leader	Longitudinal extent of decay in feet	
									Above base of dead leader	Below base of dead leader
1	82	8.7	6.0	57	29.0	1.0	20	1919	14.0	23.0
2	116	13.2	9.3	75	55.0	1.0	25	1918	10.5	20.0
3	118	13.0	4.9	55	30.0	0.5	5	1913	1.0	2.0
4	118 (77)	7.9	5.0	51	34.0	1.0	25	1923	7.0	10.0
5	80	9.6	7.3	60	39.0	0.7	6	1915	....	1.5
6	80	13.9	8.8	70	38.0	0.7	8	1915	....	1.5
7	110 (80)	11.3	7.4	65	42.0	1.0	12	1915	9.0	22.0
8	80	8.9	4.1	50	27.0	1.0	9	1920	3.0	2.0
9	96	11.5	7.0	53	31.0	1.4	23	1921	1.0	5.0
10	70	9.4	2.5	52	17.0	0.6	6	1919	....	1.0
11	90	11.0	4.2	58	23.0	1.4	21	1916	....	2.0
12	68	8.2	2.3	40	10.0	0.6	12	1921	5.0	9.0
13	92	9.4	4.2	41	18.0	1.6	14	1917	1.0	6.5
14	105	13.7	8.0	48	31.0	1.5	15	1920	....	8.0
15	100	13.0	7.0	73	32.0	2.0	18	1915	1.0	4.0
16	105 (80)	8.5	5.0	46	21.5	1.7	15	1920	2.0	10.0
17	100 (75)	12.5	6.0	65	24.5	1.3	12	1915	....	7.5
18	100 (70)	10.0	4.0	55	26.0	0.6	7	1917	....	6.0
19	105 (73)	12.4	5.0	56	15.0	2.0	21	1918	6.5	11.5

( ) = Physiological age, number of years since release from initial suppression.

have had tops killed as a result of budworm defoliation and that extent of decay was variable (1 to 37 feet in length).

All trees in Class I (forked tops; Figs. 4 and 5) and Class II (marked crook; Figs. 6 and 7) contained some measure of decay which had gained entrance into the tree through injuries resulting from budworm attack. In Class III (slight crook or sweep; Figs. 8 and 9) no decay could be definitely attributed to budworm damage. The buried leaders in 22 trees of Class III were exposed and found to be 0.5 inches or less in diameter and from one to four years old.

Tables 1 and 2 show that the killed leaders through which decay entered varied in size from 0.5 to 2.5 inches in diameter and varied in ages from 5 to 25 years.

On the basis of these findings, it would probably be safe to conclude that trees affected in the present outbreak to the extent of having their tops killed back to a diameter greater than 0.5 inches and older than 5 years will eventually contain some measure of decay in the trunk.

Discussion

No effort was made to determine the percentage of trees that contain buried leaders as a result of the previous budworm attack over large areas in the Green River Watershed. However, in small areas (one to ten acres) where growth rings were suppressed from five to ten years on the stump, approximately 10 percent of the trees con-

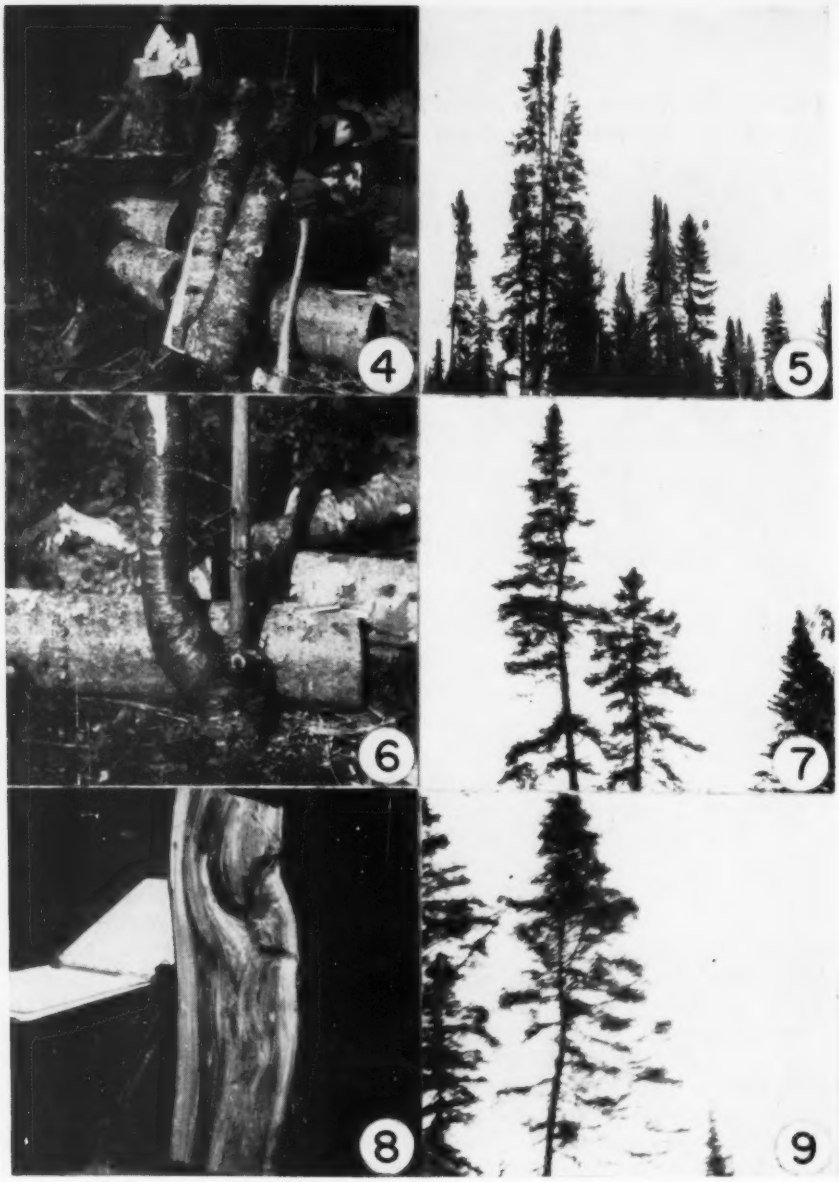

FIGURE 4. *Section from trunk of a balsam fir showing crotch that resulted from spruce budworm defoliation of 1912–1920.* FIGURE 5. *Balsam fir and spruce stand in the Green River Watershed of New Brunswick. Three trees can be seen with forked tops resulting from the spruce budworm outbreak of 1912–1920.* FIGURE 6. *Section from trunk of a balsam fir showing marked crook and a visible dead leader 35 years following the end of a spruce budworm outbreak.* FIGURE 7. *Balsam fir portraying a marked crook resulting from 1912–1920 spruce budworm attack.* FIGURE 8. *Section of a balsam fir stem, containing a slight sweep, split to show a buried leader less than 0.5 inch in diameter. Slight sweep caused by 1912–1920 spruce budworm defoliation.* FIGURE 9. *Balsam fir with a slight sweep or crook 35 years after budworm defoliation.*

TABLE 2. Description of trees crooked as a result of the 1912-1920 spruce budworm outbreak in northern New Brunswick.

Tree No.	Total age at stump	D.B.H.	Diam. at stump beginning of budworm attack	Total ht. in ft.	Ht. of fork in ft.	Diam. of dead leader in in.	Age of dead leader	Time of death of leader	Longitudinal extent of decay in feet		
									Above base of dead leader	Below base of dead leader	
20	80	6.4	4.0	50	23.0	1.5	24	1926	6.0	7.0	
21	120	10.5	7.1	65	36.0	2.5	17	1915	14.0	16.0	approx.
22	81	9.1	3.8	50	23.0	0.7	6	1914	2.0	6.0	
23	76	8.5	3.5	45	16.0	1.0	11	1918	3.0	7.0	
24	78	10.8	4.0	55	20.0	1.2	15	1917	2.0	3.0	
25	74	8.5	5.8	60	35.0	0.5	7	1915	....	1.0	
26	74	7.8	2.8	50	19.0	1.0	13	1922	2.5	3.5	
27	90	6.8	2.5	45	13.0	1.0	13	1914	6.0	11.0	
28	82	5.6	3.0	35	16.0	0.5	13	1922	....	2.0	
29	74	8.3	2.5	50	19.0	0.5	5	1916	2.0	11.0	
30	74	7.6	2.5	58	21.0	0.5	5	1922	5.0	8.0	
31	75	5.9	3.9	47	31.0	0.5	7	1918	....	4.0	
32	95	9.8	5.5	53	31.0	0.5	5	1918	....	0.5	
33	95	12.2	5.5	50	32.0	0.5	5	1922	....	1.0	
34	100?	12.1	7.0	60	41.0	2.0	12	1923	....	4.0	
35	?	9.4	4.5	60	32.0	0.6	8	1916	4.0	12.0	
36	80	8.0	3.0	56	19.0	1.3	12	1922	3.0	10.0	
37	60?	5.4	2.0	47	14.0	0.9	7	1924	4.0	13.0	
38	62	8.0	2.1	43	10.0	1.0	6	1921	4.0	6.0	

tained buried leaders larger than 0.5 inches in diameter. Until a survey is made over large areas of the Green River Watershed to determine the percentage of trees with deformities, and to measure the rate of decay in a substantial number of trees injured as a result of budworm feeding it would be difficult to estimate with any accuracy the actual volume which would be culled.

It will be a number of years before an estimate of damage to stands attacked in the present outbreak can be made. In the first place the budworm attack is not over, for according to egg counts made in the fall of 1955, many areas are still subject to heavy attack in 1956. Even when the attack has apparently subsided, weakened trees will continue to die (McLintock, 1955). Large areas will be endangered by the ever-present threat of windthrow, as occurred in the Miramichi fire area, where at least 25 percent of the spruce and 90 percent of the balsam were killed by the budworm epidemic of 1914-1920, and a severe storm in 1925 overthrew many dead and dying trees.[1]

Aerial spraying results in varying conditions which may affect the size of dead tops. Areas were not sprayed until dead tops began to appear and mortality seemed certain. If this results in less mortality than would ordinarily have occurred, more

[1]Gibson, J. M. and K. B. Brown. 1935. Summary of forest conditions on the crown lands of the Miramichi drainage north of the main south-west Miramichi River with particular reference to spruce and balsam. Unpub. rep. prepared for the Department of Lands and Mines, N. B.

trees with dead tops may survive. Whether these dead tops will be of a size which greatly increases the chance of infection (0.5 inches or larger) remains to be seen. If spraying was conducted early enough the dead leaders may be small, hence the trees would be able to heal over the damage before wood-destroying fungi enter.

After the budworm epidemic has subsided, trees with sizable (0.5 inches or larger) dead tops will be reasonably apparent. If these trees are of a fairly good size and age there should be no decay problem provided the trees are utilized within a few years, thus lessening the chance of infection through dead tops. However, if the trees are relatively young or at least of a small diameter and due to be released from suppression, then a very high percentage of these trees will be invaded by wood-destroying fungi through the dead leaders. In these particular areas it will become the problem of the forester to estimate the number of years that the stand will be allowed to put on growth before decay makes the area an economical risk.

Summary

In the spruce budworm outbreak of approximately 1912-1920 in the Green River Watershed of New Brunswick, severe defoliation caused mortality and varying degrees of top kill. The results of such injury are evident today, as deformations of the trunks. All trees that contained buried leaders five years or more old and 0.5 inches or larger in diameter were found to possess some measure of decay, which apparently had entered through or around the bases of the killed leaders. No decay could be found that had entered through or around the bases of killed leaders less than five years old and smaller than 0.5 inches in diameter. This information may prove useful in the future management of balsam fir stands surviving the present budworm outbreak.

Acknowledgments

The author wishes to express his thanks to Dr. D. R. Redmond, Forest Biology Laboratory, Fredericton, and other members of the staff, for their interest and critical reading of the paper. My thanks are due also to Dr. R. F. Morris, Forest Biology Laboratory, Fredericton, for his interest and helpful suggestions at the commencement of the work in the Green River Watershed of New Brunswick, and for his critical reading of the finished report, and to C. V. Wade, Forest Biology Laboratory, Fredericton, for his very excellent work in preparing diagrams.

Literature Cited

Belyea, R. M. 1952. Death and deterioration of balsam fir weakened by spruce budworm defoliation in Ontario. Part II. An assessment of the role of associated insect species in the death of severely weakened trees. J. For. 50: 729-738.

McLintock, T. F. 1955. How damage to balsam fir develops after a spruce budworm epidemic. U. S. Dept. Agric., Northeast. For. Exp. Sta. Paper 75.

Morris, R. F. 1946. Green River project. Canad. Dept. Agric., Sci. Serv., Ent. Div. Bi-monthly Progr. Rep. 2(3):2.

Morris, R. F., D. R. Redmond, A. B. Vincent, E. L. Howie, and D. W. Hudson. 1955. The Green River project—a decade of forestry research. Pulp Paper Mag. Can. 56(9):149-163.

Webb, F. E. 1955. Biological assessment of aerial forest spraying against the spruce budworm in New Brunswick. I. Timing of operations 1952-1954. For. Chron. 31:342-352.

Life History Studies of Five Species of Neodiprion Sawflies

BY
L. A. HETRICK

RECENT PUBLICATION of specific names for some North American pine sawflies (Ross, 1955) has prompted review of rearing records of several of these species. Biological data for these species should be of value to both entomologists and foresters. Since many of the strictly morphological characters used in sawfly taxonomy are useful only to the specialist, biological differences between species should be most helpful in aiding field workers to properly identify the insects encountered. Since most of the members of the genus *Neodiprion* are encountered as larvae feeding on pine foliage, feeding habits and larval coloration are important aids to identification.

Life history notes on the following species were obtained prior to the time that specific names were available for these insects. A previously published biological account of one of the species (Hetrick 1941) was designated under the name *Neodiprion americanum* (Leach). The taxonomic work of Ross has shown that these data apply to a previously undescribed species *Neodiprion taedae taedae* Ross.

Neodiprion abbottii (Leach)

Eighteen different lots of larvae of this species have been studied under laboratory and field conditions on loblolly pine, *Pinus taeda L.* Observations indicate three generations a year under climatic conditions of eastern Virginia. This species overwinters within cocoons on the pine needles. Adults emerge late in March or early in April and females lay eggs for the first generation. First generation larvae are feeding in May. Second generation larvae are found on infested pine trees during July and August. Third generation larvae are present from October to December and their development is retarded by low temperatures.

A striking characteristic of this species is the manner of oviposition. A female chooses a single needle of a pine terminal and places 15 or 20 eggs in a single row into that needle. The eggs are closely appressed and almost touching each other. As the eggs hatch, the larvae seldom consume the needle that contained the eggs. The needle containing the oviposition scars is frequently useful as an aid for identification of larvae of this species in the field.

Larvae of this insect are somewhat variable in their coloration. Yuasa (1922) includes *Neodiprion abbottii* in his key to the larvae of sawflies but obviously his description does not apply to larvae of this

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species as defined by Ross (1955). Head capsules of full grown larvae vary from brown to black with a light spot on the frons. Thoracic and abdominal larval coloration is pale green with 4 lateral stripes that range from dark green to black. Most heavily pigmented larvae also exhibit black scallops above the prolegs.

Larvae of this species tend to be solitary feeders in the later instars. Individuals hatched from a batch of eggs feed gregariously at first but as their size and locomotion increase, the larvae may travel some distance from the needle that contained the eggs. For this reason, defoliation is not so noticeable as in gregarious species. Cocooning takes place on the pine needles under climatic conditions in eastern Virginia.

Larval feeding under late spring and summer temperature conditions may be summarized as follows: 1st instar 7 days; 2nd instar 4 days; 3rd instar 5 days; 4th instar 5 days; 5th instar 6 days. Male and female prepupae spin cocoons on the needles and adults of the 1st and 2nd generations emerge approximately 15 days later. It is noteworthy that in this species larvae that will produce male and female adults have the same number of instars.

Since adults live only long enough to reproduce they are not likely to be encountered in the field. Adults of this species are slightly smaller and more robust than other species of Neodiprion encountered in eastern Virginia. Antennae are short in both sexes. Males are almost entirely black, but females are marked with black and pale yellow. The structure of the saw of the female is the best adult character as cited by Ross.

Neodiprion exitans Rohwer

Life-history data on this species are sketchy and have been obtained from a single group of larvae from *Pinus echinata* Mill.

A group of larvae that appeared to be in the 3rd instar was collected in King and Queen County, Virginia, on November 9. Larvae feed gregariously and cause noticeable defoliation of infested terminals. A molt was observed on November 21 and these 4th instar larvae had shiny black head capsules, and 4 black stripes on the green thoracic and abdominal background. A definite dorsal black spot was noted on the last abdominal segment of these larvae. Molting to prepupae took place in December. Obviously, larvae from which male and female adults were produced exhibited only 4 larval instars if they were correctly diagnosed as 3rd instar larvae when collected.

Cocooning took place on the pine needles. Adults emerged from these cocoons the following March and April. Since feeding larvae were found late in the season, it appears likely that this species would produce more than one generation per year. Diagnostic characteristics of the adult female have been noted by Ross.

Neodiprion hetricki Ross

Eight lots of larvae of this species were carefully studied in the laboratory. Numerous additional lots were observed in the field on *Pinus taeda* L. There is a single generation each year with adults depositing overwintering eggs in October.

Oviposition of this species is distinctive and useful in identification. A female of the species lays only one egg to a needle, but a single pine terminal may contain approximately a hundred eggs. The site of the single egg per needle is just above the needle sheath. By the following spring each egg is surrounded by a halo of dead needle tissue and the position of the eggs may be seen by the casual observer. Even after larvae have hatched and started defoliation from the tips of the needles, the sites from which the eggs hatched are still apparent.

Eggs hatch about 2 weeks prior to the shedding of pollen from staminate cones of *Pinus taeda* L. Larval feeding is entirely on needles produced during the previous growing season and may be summarized as follows: 1st instar 9 days; 2nd instar 5

days; 3rd instar 5 days; 4th instar 5 days. Larvae destined to become male adults become prepupae at the end of the 4th instar. Larvae destined to become female adults exhibit a 5th feeding instar with a duration of 8 days before transforming to prepupae. The prepupae enter the soil, where they spin cocoons. Although larval feeding is completed during early June, transformation to the pupal stage of development is delayed until the middle of September. Adults emerge from cocoons and the soil during the first two weeks of October.

Larvae of this species are variable in their markings. The head capsule is consistently black in all instars. Background thoracic and abdominal coloration is green with a pair of black dorsal stripes. In addition, a pair of black lateral stripes is evident on some full grown larvae, but in many specimens these lateral lines have broken up to form a row of black spots below the pair of prominent dorsal stripes.

Characters of the adults have been published by Ross (1955) in his description of this species.

Neodiprion pratti pratti (Dyar)

Eight lots of larvae of this species were carefully studied in the laboratory. Numerous additional lots were observed in the field as defoliators of *Pinus taeda* L. There is a single generation each year with adults depositing overwintering eggs in November.

Eggs are inserted into the sides of pine needles during the middle of November. A single needle may contain 8 or 10 eggs with an interval of approximately ¼ inch between eggs. The placement of these eggs is almost identical with that of *N. taedae taedae* Ross. By the following spring a halo of dead needle tissue surrounds each egg and terminals containing eggs can be easily found in infested areas.

Eggs hatch approximately 2 weeks prior to the shedding of pollen from staminate cones of *Pinus taeda* L. Larval feeding is entirely on needles produced during the previous growing season and may be summarized as follows: 1st instar 7 days; 2nd instar 7 days; 3rd instar 6 days; 4th instar 6 days. At the completion of the 4th instar, larvae destined to produce male adults transform to prepupae and enter the soil where they spin cocoons. Larvae destined to become female adults have an additional feeding instar with a duration of 5 days prior to transforming to prepupae and entering the soil where they spin cocoons. Although larval feeding is completed during early June, transformation to pupae within the cocoons is delayed until the middle of October. Emergence of the adults from the cocoons and the soil occurs during the middle of November.

Young larvae of this species are pale green with black head capsules. Older larvae are marked with two dorsal black stripes and two lateral black stripes. In some series the two lateral stripes have a tendency to appear as a series of irregular black spots. The black head capsule is consistent among the larvae and their appearance is similar to larvae of *N. hetrickі* Ross. The larva of *N. pratti pratti* has been figured by Craighead (1950) and Peterson (1948) under the synonymous name *N. dyari* Rohwer.

Adult males are black and cannot be distinguished from males of other species with our present knowledge. Females of this species exhibit antennae of 20 segments. The head, thorax, and abdomen of adult females are almost black with the exception of the ventral aspect of the abdomen which is pale yellow with two lateral dark bands. Ross has mentioned the practically identical saw of females of this species with the saw of females of *N. taedae taedae* Ross.

Neodiprion taedae taedae Ross

A biological account of this species was published and illustrated (Hetrick 1941) under the specific designation *Neodiprion americanum* (Leach). The error in identity of the species resulted from the confused state of the taxonomy of the genus

which has recently been clarified by the work of Ross.

Although the biological account published by Hetrick (1941) for *N. americanum* (Leach) is accurate for *N. taedae taedae* Ross, a summary of this information is included here for comparison of life-history data with other species. Numerous additional rearings were made since the 1941 publication and important findings are included in this account.

For more than 15 years this insect has been the most important defoliator of *Pinus taeda* L. in eastern Virginia. Generally the infestations are localized. Understocked old-field stands appear to be preferred, although pure stands are also sometimes defoliated. Trees 20 to 30 years of age are preferred to either younger or older trees. Pine trees valued for ornamental purposes are sometimes attacked and reports of the destructiveness of this species are received each year. Although the insect usually completely defoliates trees late in the spring, the trees appear to recover even though they have suffered repeated annual defoliation. Increment cores from infested trees exhibit reduced diameter growth for the years of defoliation.

Numerous lots of this species have been carefully studied in the laboratory and in the field. In addition, 36 larvae were reared individually in order to study more completely the development of individual insects. There is a single generation each year with adults depositing overwintering eggs during the middle of October.

The oviposition of this species closely resembles that of *N. pratti pratti* (Dyar). Eggs are inserted into the sides of pine needles about a month earlier than eggs of *N. pratti pratti.* A single needle will frequently contain 6 to 8 eggs laid in a row at intervals of ¼ to ½ inch. The unhatched eggs remain in the needles for approximately 6½ months. By spring a halo of dead needle tissue surrounds each egg and evidence of the oviposition may be seen without difficulty.

Eggs of *N. taedae taedae* hatch at the time pollen is shedding from staminate cones of *Pinus taeda* L. Larval feeding is entirely on needles produced during the previous growing season and may be summarized as follows: 1st instar 7 days; 2nd instar 5 days; 3rd instar 3 days; 4th instar 6 days. At the end of this instar, larvae destined to become male adults transform to prepupae and enter the soil where they spin cocoons. Larvae destined to become female adults have an additional feeding instar with a duration of 8 days, prior to transforming to prepupae that enter the soil to spin cocoons. Although larval feeding is completed during early June, transformation to pupae within cocoons is delayed until the middle of September. Adults emerge from the cocoons and the soil one month later to mate and deposit the overwintering eggs.

Larvae of *N. taedae taedae* have dark brown head capsules. Thoracic and abdominal body color is pale green with a pair of dark dorsal stripes and a divided dark patch on the terminal segment. Dark lateral spots are present on each segment below the dorsal stripes. The larva has been figured as *N. americanum* (Leach) by Craighead (1950), Hetrick (1941) and Peterson (1948).

Adults of *N. taedae taedae* have been described by Ross (1955) in his description of this insect and have been figured by Hetrick (1941) under the name *N. americanum* (Leach).

Factors that contribute to higher populations of *N. taedae taedae* than of the other four species are not clearly understood. Natural enemies in the form of parasites, predators, and diseases are present and do provide some degree of natural control. Perhaps the success of this species may be found in its biotic potential. Dissections of virgin females and egg counts were made in two seasons. Sixteen females from one season exhibited a range of eggs from 44 to 121 with an average of 97 per female. The following season, dissection of 40 lab-

oratory reared females showed a range of eggs from 72 to 147 with an average of 115 per female. Middleton (1921) and Benjamin (1955) have reported studies of the oviposition potential of the common and widely distributed *N. Lecontei* (Fitch), a related species and serious defoliator of young pine trees.

Since the identity of these species is now reasonably certain, additional study of egg, larval, and adult populations should contribute much to our understanding of their bionomics.

Literature Cited

CRAIGHEAD, F. C. 1950. Insect enemies of eastern forests. U. S. Dept. Agric. Misc. Pub. 657.

BENJAMIN, D. M. 1955. The biology and ecology of the redheaded pine sawfly. U.S. Dept. Agric. Bull. 1118.

HETRICK, L. A. 1941. Life history studies of *Neodiprion americanum* (Leach). Jour. Econ. Ent. 34: 373-377.

MIDDLETON, W. 1921. Leconte's sawfly (*Neodiprion lecontei* Fitch) an enemy of young pines. Jour. Agric. Res. 20: 741-760.

PETERSON, A. 1948. Larvae of insects. Part I. Edwards Bros., Ann Arbor, Mich.

ROSS, H. H. 1955. The taxonomy and evolution of the sawfly genus *Neodiprion*. For. Sci. 1: 196-209.

YUASA, H. 1922. A classification of the larvae of the Tenthredinoidea. Ill. Biol. Mono. VII. No. 4.

Experimental Design: Theory and Application

By Walter T. Federer. New York: The Macmillan Company, 1955. xix + 544 pp. Problems 47 pages. $11.00.

Review by J. G. Osborne,
Forest Service, U .S. Department of Agriculture

The importance of experimental design first received widespread attention following the initial publication of the "Design of Experiments" by R. A. Fisher in 1935. This was followed in 1937 by the "Design and analysis of factorial experiments" by F. Yates. These two publications stimulated extensive research into the development of experimental designs to cope with the problems of related experimental treatments and to meet the growing need to test larger and larger numbers of treatments, varieties, or strains simultaneously. In the 20 years following the publication of the classic works of Fisher and Yates, the literature on the subject of experimental design has not only become extensive but appears in widely scattered journals and bulletins. Federer himself has been a prolific contributor in the field of lattice designs and has been the author, or coauthor, of a series of five papers under the basic title "The general theory of prime-power lattice designs."

The author intended this book to be a textbook on experimental design, and it was written to "present subject matter and techniques not available in other texts." The result, however, is an exhaustive account of the experimental designs that have been reported throughout the literature. This reviewer feels, in fact, that the book is more an encyclopedia of designs than a textbook and will be of greatest value as such. An integral part of the presentation is the referencing page by page of the textual material to the literature cited.

As an indication of the magnitude of the task performed by Federer, some 340 books, bulletins, articles in technical journals, unpublished theses, etc., are cited in his literature review. But this is not all. If a subject is discussed in several places, all are cited. Also, the same book or paper may be referred to at several places in the text. For example, there are 120 references to 18 papers and bulletins by Yates alone.

To make the book useful as a text the author has organized the subject matter in an unusual manner. The first part of a chapter presents the design and analysis for a particular experimental design. These are followed by variations in the basic design. The mathematical model assumed and material on components of variance are presented in the last part of the chapter. Thus, as the author indicates, several types of course could be taught from this book.

As to the level of the work, the author states that the student will need to understand the basic statistical analyses and concepts as described in Snedecor's "Statistical methods" and Fisher's "Statistical methods for research workers," but that the latter reference is somewhat more advanced than is required for an understanding of most parts of the book. In my opinion, this is a substantial understatement of the preparation actually assumed by the method of presentation.

The attempt to cover the entire field of experimental design in one book even of this length has caused the introductions and explanations of the various designs to be so sketchy that they are unsatisfactory by themselves. The reader will find this book of greatest use in leading him to texts and papers in which the developments are presented more fully, and in helping him to learn from these texts. Such use is also suggested because in a great many instances the material and techniques are presented by using the examples and terminology of the author who originated or developed the technique.

Chapter II, covering the tests of significance of an array of treatment results, is very well done and brings together in useful form the scattered recent advances in this important field.

Research foresters are not likely to have extensive use for the material in this book because a need for complex experimental designs is rather rare in most fields of forestry. As previously indicated, its value as a textbook is also questioned. Nevertheless, its value as a comprehensive reference and key to the widely scattered literature on experimental designs should not be underestimated and the book should find a prominent spot in most research libraries.

Predicting Emergence of the White-Pine Weevil From Hibernation

BY
PAUL A. GODWIN
JAMES L. BEAN

RESULTS OF EXPERIMENTAL spraying for the control of the white-pine weevil (*Pissodes strobi* (Peck)) with aircraft have been inconsistent. Poor control has usually been ascribed to inadequate spray deposit or poor timing (Division of Forest Insect Investigations 1945, Bean and Smith 1949, Waters and McIntyre 1953). The variation in control results, however, indicates that not enough attention has been given to the distributional changes in the weevil population.

In early spring the weevils are in the litter beneath the host trees. As the season progresses they move to the upper portion of the crown to feed and to lay eggs. The degree and rapidity of this change must be known if satisfactory control is to be obtained.

Attempts have been made to relate weevil emergence with more obvious phenological events—principally the advance of the flora (Graham 1926, MacAloney 1930, Taylor 1929). These have not been successful, since the weevil responds more rapidly to changes in its physical environment than does the foliation or florescence of the plants that are used as indicators. Several authors have recorded air temperatures and the first appearance of the weevil, but this has not provided a workable basis for prediction (Barnes 1928; McIntyre, Bean, and Smith 1952).

The study reported here was made to determine whether the emergence of the weevils from hibernation could be correlated with temperature by a different method so that the percent of the population ascending the trees on a future date could be reliably estimated.

Investigations were conducted for 3 years: in 1952 and 1953 in two plantations of white pine at East Haven, Conn., and in 1954 in a plantation at Amherst, Mass. The average diameter of the trees, 1 foot from the base, was 2.7 inches in the East Haven plantations ranging from 1.7 to 4.2 inches. The trees at Amherst were older; they had an average diameter of 3.5 inches and ranged from 1.6 to 5.9 inches. The crowns in all plantations had closed, but openings due to tree mortality were plentiful.

The weevils were collected in traps placed on the stems of selected trees. During the emergence period the traps were examined daily in 1952 and 1953 and every other day in 1954. In 1952 a nat-

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ural weevil population was used. In 1953 and 1954 weevils (in addition to the natural population) were placed beneath the trees to be trapped. This was done in late October of the year previous to the trapping. In the spring of 1952, 254 weevils were collected; in 1953, 525 weevils; and in 1954, 1,283 weevils.

The temperature data were recorded on a Friez hygrothermograph in a weather-instrument shelter placed 12 inches above the ground.

Observations in the laboratory and field had indicated that upward movement of the weevils in the spring began within the range 35°–40° F., with movement downward at the lower temperatures. Forty degrees was then taken arbitrarily as the threshold for upward movement. The number of degrees above and below 40° was recorded at 2-hour intervals and added algebraically for a daily total. For purposes of graphing and statistical analysis these totals were tabulated cumulatively.

The emergence counts were first plotted in scatter diagrams with four temperature values: maximum daily temperature, average daily temperature, daily cumulative degrees above 40° F., and cumulative degrees above 40° F. between 6 a.m. and 6 p.m. Quadrant sum tests indicated that cumulative degrees between 6 a.m. and 6 p.m. were the most closely correlated with emergence (Wilcoxon 1949).

The weevil counts were converted to percentages. Scatter-graphs of the relationship between cumulative degrees and percent emergence indicated a curvilinear effect.

Regression analysis showed that the curvilinear effect was significant. Second-degree curves of the form $Y=b_0 + b_1X_1 + b_2X_2$ were fitted to each set of data by the method of least squares. An example is shown in Figure 1; the analysis of variance for it is given in the following tabulation.

Source	*DF*	*SS*	*MS*	*Variance ratio*	*Significance*
Cum. degrees (x)	1	19059.5	19059.5	627.9	P. 001
Curvilinear effect (x^2)	1	1943.8	1943.8	64.0	P. 001
Residual	20	607.1	30.4	.....	.....
Total	22	.....	.....	.....	.....

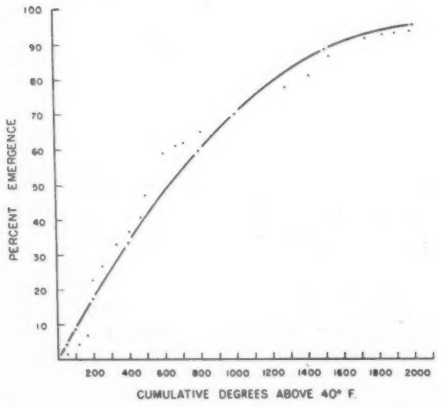

FIGURE 1. *Emergence of white pine weevils from hibernation as related to cumulative degrees of air temperature above 40° F. (Based on 1953 data.)*

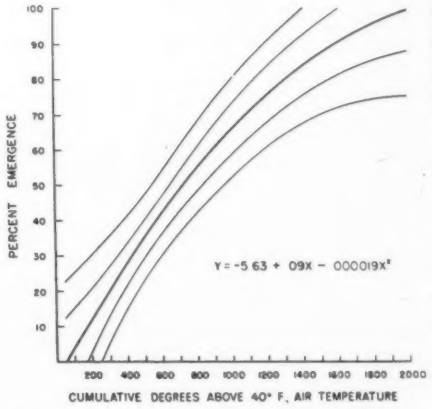

FIGURE 2. *General regression curve from pooled data, with confidence bands for 67- and 95-percent levels.*

Although there was an apparent difference between the curves, a test of homogeneity revealed no significant difference. An average curve (general regression) was then derived from the pooled data by using the same general formula. This curve, with the confidence bands for the 67- and 95-percent levels, is shown in Figure 2.

Spraying operations have usually been begun when the first weevils appeared in the spring. Control has been most successful when a second application was made a week or 10 days after the first. In the 3 years of the study period the 50-percent emergence date took place, on the average, 14 days after the first weevil was observed (18 days in one plantation in 1952 and 9 days in another plantation in 1953). If spray had been applied in these plantations 10 days after the first weevil appeared in 1952, only 11 percent of the population would have been present as compared to 50 percent in 1953. On the basis of cumulative degrees, however, only 160 degrees separate the two most widely separated 50-percent emergence dates.

Fifty-percent emergence should be expected, on the average, at approximately 730 cumulative degrees above 40° F. (Fig. 2). In practice, then, it would be expected that at 730 degrees 50 ± 6 percent (odds 2:1) or 50 ± 12 percent (odds 19:1) of the weevil population will have emerged. The average observed emergence for 730 degrees over the 3 years was 55 percent, with 4 of the 7 counts within the 67-percent confidence band and the other 3 counts within the 95-percent band. The given equation and curve thus provide a reasonably accurate and usable basis for estimating the degree and rate of weevil emergence in the spring.

Literature Cited

BARNES T. C. 1928. A biological study of the white-pine weevil with special reference to flight, oviposition, phenology, geotropism, parasites and injuries to young trees. Unpub. thesis, Bussey Inst., Harvard Univ. 143 pp., illus.

BEAN, J. L., and W. E. SMITH. 1949. Results of fall 1948 and spring 1949. Aerial spraying for control of the white-pine weevil. U. S. Dept. Agric. Bur. Ent., Div. For. Insect Invest. Sta. Rep. 5 pp. New Haven, Conn.

DIVISION OF FOREST INSECT INVESTIGATIONS. 1945. Annual Progress Report. U. S. Dept. Agric. Bur. Ent., Div. For. Insect Invest. 56 pp., illus. New Haven, Conn.

GRAHAM, S. A. 1926. Biology and control of the white-pine weevil (*Pissodes strobi* Peck). Cornell Agric. Exp. Sta. Bull. 449. 32 pp., illus.

MACALONEY, H. J. 1930. The white-pine weevil (*Pissodes strobi* Peck)—its biology and control. N. Y. St. Coll. For. Tech. Bull. 28. 87 pp., illus.

MCINTYRE, T., J. L. BEAN, and W. E. SMITH. 1952. Helicopter spraying for white-pine weevil control. U. S. Dept. Agric. Bur. Ent., Div. For. Insect Invest. Spec. Rep. 9 pp. (Processed.) New Haven, Conn.

TAYLOR, R. L. 1929. The biology of the white-pine weevil and a study of its parasites from an economic viewpoint. Entomologica Americana (n.s.) 9(4): 167-237.

WATERS, W. E., and T. MCINTYRE. 1953. Airplane spraying for white-pine weevil control in New York — 1952. Analysis of DDT deposit data. U. S. Dept. Agric. Bur. Ent., Div. For. Insect Invest. Spec. Rep. NH–1. New Haven, Conn.

WILCOXON, F. 1949. Some rapid approximate statistical procedures. Amer. Cyanamid Co. Res. Lab., Stamford, Conn. 16 pp.

Variations in Copper, Boron, and Manganese in Leaves of Pinus ponderosa

BY
JOHNSON PARKER

VERY LITTLE is known about the amounts and variations of the minor or "trace" elements in forest trees. Most of what we know of this subject comes from work done with citrus, apple, and other such crop trees. Yet certain diseases of forest trees may be a result of minor element deficiency. Increased interest in this subject is also due the apparent success of prospecting for rare or valuable minerals by sampling leaves of plants growing on certain kinds of soils which are, in turn, derived from certain kinds of rocks.

But whether we study the deficiencies in trees or attempt to prospect for minerals by leaf sampling, the question invariably arises as to what are the normal variations in leaves: how much do they vary from tree to tree on one kind of soil, how much among leaves of the same tree, and how much among different soils? It seemed worthwhile, therefore, to make a study of the minor elements of a common timber tree naturally established in the region. Such a study might also give some idea of the presence of areas where deficiencies might be expected or where certain valuable minerals might be found.

Methods

Leaves were obtained from *Pinus ponderosa* Dougl. trees from various parts of northern Idaho and western Montana as shown in Figure 1. A few samples were also obtained from the Orofino area south of Moscow. During June, one-year-old leaves were cut with a stainless steel knife from the lowest branches of trees 8 ± 2 inches d.b.h. Most of the trees selected were rather open-grown and had crowns that could be reached from the ground. Only green, normal-looking leaves were used. Excised leaves were placed in paper packets and stored in a dry place. In each location (Table 1), three or at least two trees were sampled within an acre plot, three samples from separate branches of the same tree.

During the following winter, leaves were oven-dried at 110° C. for 48 hours and weighed. After thorough washing of the hands in detergent and glass-distilled water, leaves were broken by hand into 1-cm. lengths and placed into 60 ml. capacity high-temperature silica containers and ashed at enough heat to produce a dull red glow in the furnace. Total time for the oven to reach this heat was one hour; it was then shut off and allowed to cool for five hours. Some carbon was left

This work was aided by funds from the Dept. of Biological Sciences, Univ. of Idaho. The author is much indebted to Emmet E. Spiker, Dept of Physical Sciences, University of Idaho, for arcing the samples and developing the plates. The author is now employed by the Southern Forest Experiment Station, U. S. Forest Service, Marianna, Florida.

TABLE 1. A comparison of three minor elements in Pinus ponderosa *leaves for different locations. Each value is an average of leaves from three different branches on one tree.*

Location	Rock Type	p.p.m. Copper per ash	p.p.m. Copper per dry leaf	p.p.m. Manganese per ash	p.p.m. Manganese per dry leaf	p.p.m. Boron per ash	p.p.m. Boron per dry leaf
A	Belt Series near	50	2.5±2.0[1]	1,500	68.2±25.2	1,533	77.0±85.0
	Tensed	100	6.7±1.4	1,533	102.0±22.5	2,066	135.6±57.0
B	Columbia River	70	4.0±1.3	730	39.3±21.1	1,033	64.8±21.6
	Basalt, near Lake	90	5.1±3.3	963	56.0±38.3	1,700	115.9±46.0
	Coeur d'Alene	60	5.2±1.0	397	37.3±33.4	866	78.3±17.0
C	Glacial sands and	160	5.8±1.2	1,400	51.9± 5.1	1,500	60.0±67.0
	gravels near	150	6.9±0.5	1,233	57.0± 3.5	1,250	60.1±28.1
	Athol	113	7.7±0.6	1,366	96.2±19.5	1,233	93.2±52.2
D	Sandy alluvium	153	5.2±1.5	1,550	52.9±16.2	950	34.3±12.7
	near Naples	163	4.5±1.4	1,530	43.0± 4.6	817	23.5±10.7
		62	5.4±6.0	897	82.1±53.5	966	93.5±28.8
E	Belt Series near	113	3.0±0.7	1,433	38.2± 2.3	766	20.2±10.0
	Montana Border	173	4.3±1.7	1,550	38.3±12.9	722	16.6± 8.7
F	Belt Series	173	7.5±0.9	1,583	68.2± 8.6	1,300	56.6±16.2
	near Libby	176	7.7±1.2	1,490	38.4± 2.1	550	14.9± 2.0
		181	4.7±1.4	1,617	39.8± 5.5	1,000	25.1± 4.4
G	Columbia River	220		1,500		2,166	
	Basalt, near	112		1,150		1,233	
	Orofino	116		300		1,600	
H	Idaho Batholith	220		300		1,200	
	near Kamiah	113		127		1,400	
		153		1,200		2,833	

[1]Indicates the greatest variation from the mean in the three samples averaged.

by this procedure. The purpose of not ashing to the point where all carbon was removed was to avoid loss at high temperatures of such elements as manganese. A comparison of leaf powders heated to the point where no carbon was left with those containing carbon showed some pronounced differences for certain elements. This was evidently due to the loss of a large part of such elements, including manganese, in the oven when a white, carbon-free powder was obtained by heating to a higher temperature and only to a small extent due to different arcing characteristics produced by the carbon. In other words, it was not the carbon quantity in the sample that caused the difficulty, but the loss of certain minerals in obtaining the ash or powder.

The ignited leaf material was taken from the oven and weighed, then ground with an agate mortar and pestle to a fine powder. A sample of this was placed in a weighed carbon electrode having a crater at one end with an inside diameter of 3 mm. and a crater depth of 2 mm. Ten mg. ± 3 mg. of this powder was forced into the crater by holding the carbon upside down at the base and tamping some of the powder into the crater or pouring it from above from waxed paper in cases where it would not pack. Each carbon with its powder was then weighed in an upright position by placing it in an aluminum holder that fitted on the microbalance pan. Powder weight was then adjusted to 10 ± 1 mg.

Standards were made for copper, man-

ganese, and boron as follows. A standard base powder was made consisting of 9.6 percent SiO_2, 53.7 $CaCO_3$, 27.8 K_2CO_3, and 8.9 M_gO by weight. These proportions were originally derived from Lutz and Chandler (1946) for various kinds of leaves and further corrected by comparison to preliminary arcings of ponderosa pine leaves. For compounds which make up the bulk of the material, however, the spectrograph cannot be expected to be so accurate as, for instance, the spectrophotometer (Nitchie, 1929). All ingredients were spectrographically pure compounds within certain specified limits obtained from Johnson and Mathey Co., Ltd., through Jarrell-Ash Co., Newtonville, Mass., and were ground in agate before mixing in pyrex jars.

Copper sulfate, manganese sulfate, and boric acid, "spec pure" were ground separately, weighed, and added to certain amounts of the base powder, then mixed and diluted with further additions of base powder to known concentrations. The importance of using a base powder resembling the plant ash was shown by Vanselow and Liebig (*circa* 1950). They pointed out that the amount of one compound affects the burning characteristics of others. On the other hand, these oxides and carbonates are more likely to burst out of the electrodes during arcing than certain other mixtures.

Powders were arced in the carbons for one minute at six amperes and 220 volts, the resulting energy passing through a filter system giving one-third (33 percent) transmittance and into a Wadsworth grating spectrograph, the principle of which is described by Devlin (1952). From this instrument two plates were obtained, one in the range 2288 to 3500 Å, the other 3500 to 4800 Å. The uppermost exposure of each plate represented the arcing of an iron electrode for line positioning, the next five exposures were standard powders, and the remaining 12 represented leaf powders. Kodak spectrum analysis no. 1 plates (4 × 10 inches) were used and were developed in Kodak D-19 for three minutes at 22° C. in an automatically rocking tray, stopped in dilute CH_3COOH, fixed for two minutes, and washed in tap water for a half hour before drying. A Jarrell-Ash recording densitometer was used to measure line density and unknown line densities were compared to lines from known powders (Brode, 1943).

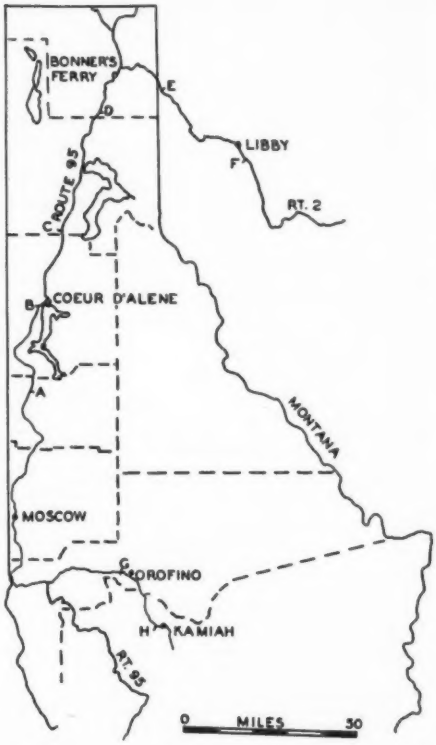

FIGURE 1. *Map of North Idaho. Dashed lines represent county borders. Letters (A-H) represent sampling points.*

Results

The data presented in Table 1 show that in a few cases there is a tendency for the minor elements to be either high or lower

TABLE 2. A comparison of amounts of copper, boron, and manganese in leaves of various plants, expressed as parts per million of dry weight.

Element	Reference	Plant	Normal	Deficient
Boron	Robinson and Edgington	Hickory	18-84	
	Stone and Baird	Pine	30-140[1]	
	McLarty *et al.*[2]	Apple	9.7-27.6	2.3-9.3
	Ferrell[3]	West. white pine	33	15 (diseased)
	Lehrer and Jordan	Apple	17-18	9-11
	Jordan	Alfalfa	15	>12
	Walker *et al.*	West. red cedar	33-104	>15
	Parker (this study)	Ponderosa pine	c. 14-135	
Copper	Lehrer and Jordan	Grape	7.5-9.9	2.1-5.4
	Jordan	Pasture	7.5	>7
	Bould	Apple	5.0-7.9	1.4-3.0
	do.	Pear	8.0	1.1
	do.	Cherry	14.2	3.1
	Haas and Quayle	Orange	8.14-21.4	>6.8
	Dunne	Apple	3-12	1-3.6
	Riou *et al.*	Broad-leaved trees	7.1-11.8	
	Warren and DeLavault	Stems of conifers	3-26	
	Parker (this study)	Ponderosa pine	c. 2.5-7.9	
Manganese	Lehrer and Jordan	Apple	55-125	5
	Jordan	Pasture	20	>10
	Parker (this study)	Ponderosa pine	c. 38-102	

[1]Toxic. [2]Cited by Anon., 1948. [3]Unpublished data, School of Forestry, University of Idaho.

in one location than in another. However, the data show no statistically significant differences among locations at a probability level of 0.95. When data are calculated on a basis of oven-dry weight, there is even less difference among different locations. The reason why the data based on ash and that based on dry leaves are different is due to the different amounts of ash per leaf in different samples.

Copper averaged 5.4 p.p.m. on an oven dry weight of leaf basis, varying about 2.5 above or below this. Manganese showed a wide scattering of data from about 38 to 102 p.p.m. with an average at 56.8. Boron showed the widest scattering of data from about 14 to 135 with an average at 60.2. These compare favorably in order of magnitude with data of other workers (Table 2). Actually, however, these ranges of concentration so often given in the literature are not very meaningful since the range given becomes greater as more samples are obtained. A much better idea of the true distribution of the data can be obtained from a frequency diagram like that given by Warren and Delavault (1955a). We therefore include Figure 2 to show that boron occurs as a much skewed type of frequency while copper and manganese seem grouped more evenly around the mean.

It might be suspected that much of the variation in results is due to experimental error. But this cannot be the case. Table 3 is included to show the usual variation encountered in arcing two samples from the same powder. The spectrographic method, then, does not incur an error of much more than 10 percent on the average. The slight error involved in the ashing process cannot add more than another 5 percent to the spectrographic error. Differences between two different branches,

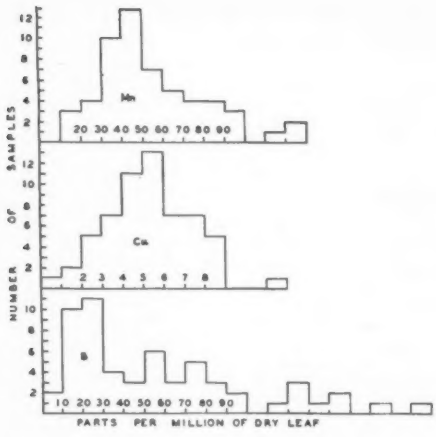

FIGURE 2. *Distribution of data for manganese, copper, and boron. Number of samples has been plotted over parts per million of oven-dry leaf. "Number of samples" in the diagram refers to the number falling in each group, eg., 0-10, 10-20 p.p.m., etc.*

however, varies from as little as 8 to as much as 28 p.p.m. of boron in one tree (Table 3). Differences among different trees on the same soil also may show much wider variations than would be accounted for by the experimental error (see for instance, copper, manganese, and boron in location A, Table 1).

In spite of the apparent lack of difference among different trees and different locations, there does seem to be enough similarity among branches of the same tree so that differences among different trees are often nearly significant. Although statistical analysis at a level of 0.95 shows no significance, it will be noted that in Table 3 the data for all elements in Trees 2 and 3 do not overlap, but are substantially different. In the preliminary arcings, the similarity of different branches on the same tree could often be seen directly on the plates with the naked eye at a glance.

The difficulty of locating such elements as silver and gold on the plates exposed for boron, copper, and manganese is that the former group are so weak that they are very difficult to see at all. We therefore used 100 percent transmittance on some samples from locations E and F and identified the following elements: Pb, Ti, Cr, Pt, Rb, Fe, Al, Ag, Mo, Sn, Na, Ga, and various major elements. Fe and Al showed up clearly on all plates at one-third transmittance, but the others were mostly very weak at 100 percent. No difference in the two locations could be seen by eye. As, Be, Au, Zn, Tl, and Os could not be seen on any plates.

Discussion

Minor element deficiencies have been known in herbaceous crop plants for about

TABLE 3. Variability of paired samples. Each pair represents two separate arcings from the same powder made from a single leaf sample.

Tree	Sample	Copper	Manganese	Boron
		p.p.m. based on leaf dry weight		
Location 1	a	4.4	43.6	18.5
Tree 1	a	5.0	39.6	15.8
	b	5.8	51.2	28.8
	b	5.3	46.4	19.2
	c	2.6	23.7	7.9
	c	2.7	25.3	9.5
Location 2	a	6.9	68.7	40.4
Tree 2	a	7.1	64.6	40.4
	b	7.5	59.6	55.6
	b	6.6	59.6	51.6
	c	8.3	78.4	78.4
	c	8.3	78.4	73.5
Location 2	a	4.1	34.5	20.7
Tree 3	a	4.1	34.3	20.7
	b	5.1	38.1	23.0
	b	4.1	39.7	23.0
	c	6.0	46.8	36.2
	c	4.4	45.0	27.2

a half century but it is relatively recently that they have been found to be so important in many kinds of trees (Anon., 1948). Although data were collected on minor elements in trees prior to 1917 (Pichard, 1898; Miller, 1938), the work of Flody (1917) with citrus trees is considered by many to be the starting point. After that, many minor elements were found deficient in crop trees, especially during the 1930's with apple, orange, pecan, and many others. The work on forest trees is relatively small and comes mainly from the Canadians such as Gamelin in 1937 and Riou *et al.* (1941) and the Australians such as Smith (1943) and Stoate (1951). It is clear that conifers as well as broad-leaved trees growing either as native trees or as exotics often suffer from minor element deficiencies. Furthermore these analyses seem to reflect to some extent the quantities in the soil and thus in the rocks in cases where the soil has unusually high or low levels of certain elements (Kennedy, 1952; Warren *et al.*, 1953; Warren and Delavault, 1955a, 1955b; Cannon, 1953).

Due to the general lack of information on forest trees in Idaho we have to draw much information from crop trees which are not native to the area and whose soils are often old agricultural land depleted by other crops. It is therefore of doubtful value to consider the behavior of such plantations as apple orchards as typical of a particular area. On the other hand some idea can be obtained of the relative amounts of minerals considered to be deficient or normal for those trees. In table 2 are presented the results of various workers. Conifers apparently respond roughly as do other woody plants to the various elements in the soil (Nemec, 1936; Pessin, 1937; Hobbs, 1944) so that certain comparisons seem justified between crop trees and conifers. However, Haas and Quayle (1935) pointed out that there is so much overlapping of data from different trees that selection of any particular level for, say, copper in citrus leaves, does not mean a great deal. They especially emphasize the importance of proper controls in making such comparisons since a level of copper that may be harmful to one tree may be apparently normal for another.

In any case, any one of the three elements studied in the present paper are known to cause, by their lack, certain diseases of various crop trees. Copper deficiency is well known in crop trees. Dieback of apple trees (Dunne, 1938), exanthema of citrus trees (Flody, 1917; Fudge, 1934), of pears (Oserkowsky and Thomas, 1933), and of prunes, apples, pears, and olives (Smith and Thomas, 1928; Bould, 1954) has been established as copper deficiency and can often be corrected by applying copper in certain ways to the tree or soil (for example, Cahill, 1929; Thomas, 1931).

Boron deficiency in fruit trees is also well established. McLarty *et al.* (Anon., 1948) reported the effects on apple trees and Robinson and Edgington (1942) on hickories, pointing out that amounts of boron in the leaves of hickories may be twice as much in autumn as in spring. Some data is also available for pines. The data of Stone and Baird (1956) for boron in *Pinus resinosa* and *P. strobus* showed that differences in soil and in time of sampling did not affect results. However, additions of boron to the soil were clearly reflected in the amounts found in the leaves (Table 2). They were able to produce boron toxicity by adding excess borate to the soil. Resulting symptoms included browning or drying of the current leaves. This is evidently different from results produced by Ludbrook (1940, 1942) with pines in water culture which were lacking in boron. Ludbrook described reduced growth rate, followed by cessation of growth in tops and death of young needles.

In the case of manganese we again have only a little information, but certain facts have been learned. Pichard (1898) studied manganese content in various plants and

animals and concluded that, of the gymnosperms, the conifers were richest in manganese. Deficiency of this element was found associated with chlorotic leaves of pin-oaks in Kentucky (1926 cited by Anon., 1948) and Nemec (1936) pointed out that tree seedlings growing in soils with pH higher than 5.2 were likely to contain little manganese. A survey of forest tree leaves for manganese was made by McHargue and Roy (1932), Gamelin (Anon., 1948), and Riou *et al* (1941, 1942). These results showed a species difference in various conifers for manganese and when these different species were found growing on a similar soil they still showed the differences. However, cedars such as white cedar (*Thuja occidentalis*) which were low in manganese were often found naturally on calcareous soils, so that manganese might not be so available on these soils. Gamelin (Anon., 1948) concluded that black spruce (*Picea mariana*) and tamarack (*Larix laricina*) were highest in manganese and white cedar was lowest among conifers.

It appears from the foregoing and from data here presented that trees have a remarkable ability to adjust these minor elements to certain levels so that minerals in the soil are not so well reflected in the leaves as might be expected. As time goes on, many of the minerals continue to accumulate in the leaves but the general relative proportions, judging from our plates, do not change a great deal. In other words the older leaves have much more ash per leaf, but the general proportion of minerals seems about the same. Certain exceptions to this of course occur, for instance, sodium/calcium ratios change with age (so it appears from our data), a fact perhaps related to the ability of the leaves to transport out some minerals in the phloem. It would seem that only on widely different kinds of soils or soils with radically different mineral levels are these anomalies reflected in the leaf samples.

Supposing that unusually low levels of minor elements in the soil can be reflected in data from normal-appearing leaves, there is no outstanding indication of mineral deficiencies in any particular area studied. Perhaps the general occurrence of loessial drift in many parts of northern Idaho which is often mixed with soil formed in place may account for this general lack of location difference. Taking the region as a whole, however, our data resemble Jordan's (1955) to some extent. He found deficiencies of copper and boron but not of manganese in alfalfa and pasture in many parts of Idaho; our trees showed several cases of low copper and boron amounts but no low ones for manganese (Table 2). In this connection it has been suggested that "Pole Blight" of western white pine (*Pinus monticola*) is a result of mineral deficiency, but Ferrell[1] is inclined to think that his low values shown in Table 2 for boron are the result rather than the cause of the disease. It seems to us that recurrent drought is a possibility also worth considering in white pine.

Summary

Spectrographic analyses for copper, manganese, and boron were made in leaves of ponderosa pine from various parts of northern Idaho and adjacent Montana. Copper averaged 5.4 p.p.m. on a leaf dry weight basis, manganese 56.8, and boron 60.2. In comparison to work of others copper and boron levels are often rather low, but manganese never so. Nevertheless, the data vary widely for each mineral, especially boron. When plotted as frequency diagrams the data show a pronounced skewed curve for boron and rather normal frequency curves for the other two.

Differences among different trees are strongly suggested but not statistically proven to be significant. Values for leaves from different branches vary widely but this is far in excess of the experimental

[1]Unpublished data, Univ. of Idaho, Moscow.

error. Differences among different locations are suggested by the data but are so overlapping and have such large variance that statistically significant differences are not indicated.

In general the data suggest no particular deficiency areas for these three minor elements, nor do they show any particular accumulations of certain elements such as gold. Traces of a number of valuable elements including Pt, Sn, and Ag were present in many leaves. In general it appears that the trees are able to adjust themselves to certain levels to a remarkable extent in spite of the various kinds of soils on which they are growing.

Literature Cited

ANON. 1948. Bibliography of the literature on the minor elements and their relation to plant and animal nutrition. 4th Ed., Vol. 1 (with suppl. Vol. 2, 1951) Chilean Nitrate Educational Bureau, Inc., 120 Broadway, N. Y. 5, N. Y.

BOULD, C. 1954. Copper and zinc deficiencies in soils and fruit trees. Internat. Congrès de Paris 1954. Sec. 11 & 12: 92-98.

BRODE, W. R. 1943. Chemical spectroscopy. 2nd Ed. John Wiley & Sons, Inc., London.

CAHILL, V. 1929. Experiments for the control of exanthema in Japanese plum trees. Jour. Dept. Agric. West. Australia 2, ser. 6:388-394.

CANNON, H. L. 1953. Geobotanical reconnaissance near Grants, New Mexico. U. S. Geol. Surv. Circ. 264 pp. 1-8.

DEVLIN, J. J. 1952. The spectrograph in modern industry. Reprinted from Sci. Couns., June. Duquesne Univ. Press, Pittsburgh, Pa.

DUNNE, T. C. 1938. "Wither Tip" or "Summer Dieback,' a copper deficiency disease of apple trees. Jour. Dept. Agric. West Australia 15: 120-126.

FLODY, B. F. 1917. Dieback, or Exanthema, of citrus trees. Florida Agric. Exp. Sta. Bull. 140.

FUDGE, B. R. 1934. Dieback of citrus. Florida Agric. Exp. Sta. Ann. Rept. 1933: 137-138; 1934: 81-82.

HAAS, A. R. C. and H. J. QUAYLE. 1935. Copper content of citrus leaves and fruit in relation to exanthema and fumigation injury. Hilgardia 9: 143-177.

HOBBS, C. H. 1944. Studies on mineral deficiency in pine. Plant Physiol. 19: 590-602.

JORDAN, J. V. 1955. Protein and mineral content of forage legumes and grasses in Idaho. Univ. Idaho Agric. Exp. Sta. Bull. 245. October pp. 1-8.

KENNEDY, V. C. 1952. Geochemical studies in the Coeur d'Alene mining district, Idaho. U. S. Geol. Surv. Circ. 168 pp. 1-15.

LEHRER, W. P., JR., and J. V. JORDAN. 1955. Microelements for plants and animals. Univ. Idaho Coll. Agric., Moscow. pp. 1-15. mimeo.

LUDBROOK, W. V. 1940. Boron deficiency symptoms on pine seedlings in water culture. Jour. Counc. Sci. Ind. Res. (Australia) 13: 186-190.

————. 1942. The effects of various concentrations of boron on the growth of pine seedlings in water culture. Jour. Austral. Inst. Agric. Sci., 8: 112-114.

LUTZ, H. J. and R. J. CHANDLER, JR. 1946. Forest soils. John Wiley & Sons, Inc., N. Y.

MCHARGUE, J. S. and W. R. ROY. 1932. Mineral and nitrogen content of the leaves of some forest trees at different times in the growing season. Bot. Gaz. 94: 381-393.

MILLER, E. C. 1938. Plant physiology. McGraw-Hill Book Co., N. Y.

NEMEC, A. 1936. Beitrag zur Kenntnis der Mangel- ("Kanenz") Erscheinungen bei Kiefernsämlingen. Forstwiss. Centrbl. 58: 798-808.

NITCHIE, C. C. 1929. Quantitative analysis with the spectrograph. Ind. Eng.

Chem. Anal. Ed. 1: 1-7.

OSERKOWSKY, J. and H. E. THOMAS. 1933. Exanthema in pears and its relation to copper deficiency. Science 78: 315-316.

PESSIN, L. J. 1937. The effect of nutrient deficiency on the growth of longleaf pine seedlings. U. S. For. Serv., Southern For. Exp. Sta. Occ. Pap. 65.

PICHARD, P. 1898. Contribution à la recherche du manganèse dans les minèraux, les vègètaux, et les animaux. (Contributions to investigations on manganese in minerals, plants, and animals.) Compt. Rend. Acad. Sci. de Paris 126 (26): 1882-1885.

RIOU, P., G. DELORME, and F. SYLVESTRE. 1941. De la répartition du cuivre dans les arbres à feuilles caduques du Québec. Ann. Assn. Can. Fran. Avanc. Sci. 7: 73.

———. 1942. Variations de la teneur en cendres et en cuivre des organes décidus de quelques arbes, au cours d'une année. Ann. Ass. Can. Fran. Avanc. Sci. 8: 77.

ROBINSON, W. O. and G. EDGINGTON. 1942. Boron content of hickory and some other trees. Soil Sci. 53: 309-312.

SMITH, M. E. 1943. Micronutrients essential for the growth of *Pinus radiata*. Austr. For. 7: 22-27.

SMITH, R. E. and H. E. THOMAS. 1928. Copper sulphate as a remedy for the exanthema in prune, apples, pears, and olives. Phytopath. 18: 449-454.

STOATE, T. N. 1951. Nutrition of the pine. Forestry and Timber Bur., Bull. 30. Canberra, Australia.

STONE, E. L. and G. BAIRD. 1956. Boron level and boron toxicity in red and white pine. J. For. 54: 11-12.

THOMAS, H. E. 1931. The curing of exanthema by the injection of copper sulphate into the tree. Phytopath. 21: 995-996.

VANSELOW, A. P. and G. F. LIEBIG, JR. *circa* 1950. Spectrochemical methods for the determination of minor elements in plants, water, chemicals, and culture media. Univ. Calif., Agric. Exp. Sta., Berkeley 4, Calif. mimeo.

WALKER, R. B., S. P. GESSEL, and P. G. HADDOCK. 1955. Greenhouse studies in mineral requirements of conifers: western red cedar. For. Sci. 1: 51-60.

WARREN, H. V., R. E. DELAVAULT, and D. G. ROUTLEY. 1953. Preliminary studies of the biogeochemistry of molybdenum. Trans. Roy. Soc. Can. IV, 47: 71-75. (Chem. Abstr., 1954).

WARREN, H. V. and R. E. DELAVAULT. 1955a. Some biogeochemical investigations in eastern Canada. Can. Mining Jour., July-Aug. pp. 1-12.

———. 1955b. Biogeochemical prospecting in northern latitudes. Trans. Roy. Soc. Can. Ser. Sec. IV, 49: 111-115.

Optimum Intensity of Forest Land Use on a Regional Basis

BY
ALBERT C. WORRELL

THE FOREST LANDS of the United States can produce many goods and services which our people desire. For years we were content to harvest what nature produced and did practically nothing to increase the yield from these lands. Now we generally accept the idea that more intensive use of our forest lands is justified, but we are not sure how much more intensive our use should be or what form the intensification should take. This uncertainty exists partly because forest land is only one of our resources and forest products form only a small part of the goods and services we wish to consume. More intensive use of our forest land resource would require labor, capital, and managerial ability which we might use instead to produce some other desirable goods or services. How much of these productive resources should we devote to forestry, and in what combinations? At what optimum intensity of use will forest land make its best contribution to our total satisfaction?

Optimum intensity of forest land use is the subject of this study. The concept of an optimum is well established in many fields of knowledge; it has been defined and serves as a useful reference standard against which existing states of affairs can be evaluated. Our first task, therefore, is to define an "optimum intensity of forest land use." Immediately we find ourselves confronted by the question: optimum for whom? In this particular study we are concerned with planning resource use for the benefit of society as a whole. We thus will be considering a social optimum and can restrict the concept under study to an "optimum intensity of forest land use on a regional basis."

A fundamental difficulty in determining optimum intensity is that we cannot hold everything else constant while we vary forest land use. Our second task is to identify variables which influence the optimum intensity of forest land use. Merely listing them is not useful because they are interrelated and react upon each other. An understanding of these interrelationships is needed.

The real value of the concept of an optimum is to guide action. Our final objective, therefore, is to determine how the concept of an optimum intensity of forest land use on a regional basis might aid in the formulation and administration of conservation programs.

This is an exploratory study. In it I am not concerned with determining the actual optimum intensity of forest land use for some specific region. But to keep from engaging in a purely theoretical exercise I am

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using a real area as the subject. In terms of land use, a region is a large area with a pattern of major characteristics which differs from that outside its boundaries. For this study I needed a region with variability in the amount and distribution of those characteristics which have a major effect on land use. A small region with variable conditions would be just as useful as a large one. I therefore selected ten Piedmont counties around the city of Athens, Georgia, as my sample region. This is primarily an agricultural area of small private landholdings and exhibits many land use problems not encountered in more heavily forested areas. The total area of the ten counties is 1,623,700 acres, the forest land area in 1953 was 782,700 acres, or 48 percent (McCormack and Cruikshank, 1954). The predominant timber species are loblolly and shortleaf pines, which make up 53 percent of the growing stock. Less than one percent of the timberland in the area is in public ownership, and in 1950 the Bureau of the Census (1952) found that 85 percent of the land area was in farms.

Because of the nature of this study, highly reliable data are not necessary and the figures used here were obtained wherever available with only a limited amount of field sampling to fill in major gaps. Definite conclusions about this specific area cannot be drawn from this study, but the data used are typical of what would be encountered in an actual determination of optimum intensity of forest land use in a similar region. Since the practice of forestry in this area is too young to have final answers to many technological problems, the silvicultural practices used in this model have been based on the best judgments of foresters familiar with the area. In order to reduce the variables to manageable proportions, I had to make many simplifying assumptions, such as that even-aged management is best for all forests in the region. These simplifications have no real significance in light of the objectives of the study.

As the harvesting, marketing, and utilization of forest products involve many problems which are not directly a part of land use, it seemed best to restrict this study to the production of the forest crop. It is assumed throughout that the trees are sold on the stump and that costs of harvesting are borne by the purchaser. All prices used here are stumpage prices, and all costs are those involved in growing trees to the point where they are ready to be harvested.

Fundamentally, this study consists of the application of the theoretical economic tools of efficient resources use to an analysis of the use of an actual resource—forest land. The analysis starts with a highly simplified situation in which most of the problems of land use are assumed away. Reality will be approached by steps, in each of which a new set of variables is introduced. Although the analysis is primarily economic, we will recognize non-economic variables in the final stages.

Long-Run Efficiency in Forest Land Use

Forest land use in any region is influenced by many factors. Some of these, like ownership, are of a transitory nature or are subject to change by man. Others, such as land productivity, are practically permanent and must be accepted as fixed characteristics of the region. In this part of the analysis we will assume away the changeable factors and investigate optimum intensity of land use with only the permanent factors considered. This will give us a potential or idealized version of efficient forest land use in the Region. Since in the long run the temporary factors can be changed, this potential efficiency might form a goal or guide for land use adjustments.

Wood products are the major values produced by the forests of the Region. These forests also serve as watersheds by encouraging infiltration and provide a habitat for wildlife, but there is little recreational use. In general, wood production in this Region is compatible with other for-

est uses, and managing the forest land for this purpose will not involve social costs through loss to the public of other values. Management of these lands for wood production will produce social revenues in the form of watershed protection and wildlife habitat which cannot be recovered by the landowner. These social revenues are difficult to measure and are not included in the following analysis. They are recognized implicitly in our general assumption that the public is justified in providing forest fire protection at public expense and in assisting the private landowners with their forest management.

For this part of the analysis we temporarily will make three assumptions: (1) no problems of ownership and present condition of forest stands exist, (2) management intensity can be adjusted to any level immediately without going through a transition stage, and (3) the factors of production are available in unlimited quantities at going prices and forest products can be sold in unlimited quantities at prevailing prices. We will relax these assumptions later in our analysis.

The forest land productivity classes. From a commercial viewpoint, the pines are the important timber species in the Georgia Piedmont, the upland hardwoods being generally of poor quality. We will accept the growing of pine as the proper objective of management in this model. In the river bottoms, sweetgum and other valuable lowland species grow well and pine can be grown only with difficulty. Rational forest management dedicates these lowlands to hardwood production, but little is known about the management and yield of these hardwood forests. Since they make up only a relatively small part of the forest land of the Region, and information on them is sketchy, it seems best not to include them in this analysis.

Pine can be grown on all uplands in the Region but the productivity of these lands varies considerably, due in part to natural differences and in part to past agricultural use. Productive capacity occurs in all graduations from good to very poor. In order to restrict this variable to manageable proportions, we will divide these forest lands into four major productivity classes. This classification is based on site index—the average total height of dominant and codominant trees at fifty years of age—which permits us to use existing yield tables in our analysis. My field observations showed no correlation between site index and factors which affect the cost of silviculture, such as the degree of hardwood invasion, the adequacy of natural restocking, and conditions interfering with cultural work. This means that we can use the same silvicultural costs on all classes except for the capital costs which naturally will vary with the length of the rotation. The productivity classes differ in the length of time required to produce merchantable trees, the total volume of wood produced per acre, and the species of trees naturally associated with the class.

The productivity classes which we will use in this study and their associated species in order of importance are as follows:

Class 80: site index 80; loblolly pine, shortleaf pine, red oaks, sweetgum, white oaks

Class 70: site index 70; loblolly pine, shortleaf pine, sweetgum, red oaks, hickories, white oaks

Class 60: site index 60; shortleaf pine, red oaks, hickories, loblolly pine, white and post oaks

Class 50: site index 50; shortleaf pine, red oaks, hickories, post and white oaks.

The levels of management intensity. Management of forest lands may vary from simple fire protection to intensive use of all applicable silvicultural techniques. The gradation between these extremes may consist of both the successive application of additional techniques and the more intensive use of individual techniques. Thus there are a great number of possible intensities of management. In order again to

restrict a variable to manageable proportions, we will divide management intensity into four broad classes.

Since we are not interested here in comparing silvicultural systems, we will select one system and use it throughout the analysis. Foresters rather generally agree that pine can be grown best in the Georgia Piedmont under even-aged management. There is also considerable agreement among those familiar with the Region that satisfactory reproduction can be obtained from sawtimber stands by the two-cut shelterwood method, leaving between two and three thousand board feet in the shelterwood stand. We will use this method in our model with two exceptions. In pure hardwood stands the clearcutting method is used. In pine-hardwood stands with little pine, the seed tree method is used, leaving about one thousand board feet in pine seed trees.

Because it appears that all forest lands in the area will receive adequate public fire protection, we take this as the lowest level of management intensity. The second level of intensity is patterned after prevailing service forestry programs—the stand is marked for cutting at harvest time but no other cultural work is done. For the third level of intensity we add sufficient cultural work to assure a reasonable reproduction of pine and include commercial thinnings. This is the minimum level which will maintain pure pine forests in the area because of the natural reversion to hardwoods. For the highest level we intensify the cultural work enough to insure full stocking of pine reproduction, use more frequent thinnings, including a precommercial thinning, and prune crop trees to produce quality sawtimber. This top level includes all cultural practices which appear silviculturally feasible for pure pine management in this area. The levels of management intensity which we use in the analysis and their main features are shown in Table 1.

The costs of management. The management costs used in this analysis include all direct costs, both public and private. Because the viewpoint of the analysis is that of the region as a whole, full public costs are included. For example, the figure used for the cost of planting stock is the actual cost to the State of growing the seedlings rather than the price at which they are sold to private landowners. Management costs vary widely from one property to another. Those used in the analysis are averages of the best estimates I could get from foresters who are managing land under conditions similar to those in the study area (Worrell, 1953). Common labor is calculated at $0.75 per hour and technical labor at $2.50 per hour. (The technical labor figure is intended to include the ordinary expenses of the technician.)

Table 2 shows the costs used in the analysis. We assume that the timber to be sold is cruised under all levels of management and include a figure of 30 cents per acre to cover the cost of cruising and selling. Management at Levels I and II involves so many operations that the manager must devote some time to general supervision not directly connected with any specific operation. To allow for this, a figure of 20 cents per acre per year is included in the cost determination for these two levels. The figures in Table 2 are used directly in the calculations with a few exceptions. Because scarification of the entire area is not called for at any level, the scarification cost is reduced to $4.80 per acre under Level I, and to $3.50 under Level II. Natural reproduction should be adequate most of the time and reinforcement planting may be needed in only ten percent of the cases. When averaged over all lands, this gives a reinforcement planting cost of $1.40 per acre under Level I, and of $0.65 under Level II. Since full stocking of reproduction may not be obtained every time even under Level I Management, we can assume that the precommercial thinning will be needed in only

TABLE 1. Silvicultural operations for various levels of management intensity.

Management intensity level	Silvicultural operation	Timing of operation
IV	Fire protection	Every year
	Harvest by clearcutting	Rotation age
III	Fire protection	Every year
	Harvest by seed tree method	Rotation age
	Remove seed trees	5 years
II	Fire protection	Every year
	Harvest by shelterwood method	Rotation age
	Scarify 50 percent of area	0 years
	Poison hardwoods over 6 inches DBH	0 years
	Remove shelterwood stand	5 years
	Release 300 seedlings per acre	5 years
	Interplant to give 300 seedlings per acre	5 years
	Commercial thinnings when average tree is 7 inches DBH and yield 5 cords per acre	At 10-year intervals
I	Fire protection	Every year
	Harvest by shelterwood method	Rotation age
	Scarify 80 percent of area	0 years
	Poison hardwoods over 3 inches DBH	0 years
	Remove shelterwood stand	5 years
	Release 600 seedlings per acre	5 years
	Interplant to give 600 seedlings per acre	5 years
	Thin (precommercial) to 500 trees per acre	15 years[1]
	Prune 100 trees per acre	15 years[1]
	Commercial thinnings when average tree is 6 inches DBH and yield 2 cords per acre	At 5-year intervals

[1]At 25 years on productivity class 50.

ninety percent of the cases, giving an average cost for this operation of $4.50 per acre.

The choice of products and species. So long as we assume that the market will absorb at prevailing prices any quantity of any product, it is not hard to decide what to produce. The price differential between pine sawtimber and either upland hardwood sawtimber or pine pulpwood is so great that with present prices it is more profitable to grow pine sawtimber than any other product, regardless of the quality of the land used. Our analysis, therefore, is built around the aim of producing pine sawtimber. Pulpwood is produced only as a byproduct from thinnings, and hardwood timber is produced only when the level of management will not produce pine.

The Yield under Management.

Volume yields. We do not have in the United States today tables which show the yield of products at various ages for forests under management. So special yield tables for this study were derived from published normal yield tables for unmanaged forests. The adjustments for the effect of the different levels of management are based on observation and experience in the region and both the process of adjustment and

TABLE 2. Average forest management costs per acre.

Operation	Labor *man hours*	Technician *man hours*	Total costs[1] *dollars*
Fire protection	0.07	0.02	0.15[2]
Property taxes			.30[2]
Marking trees for cutting			
Shelterwood or seed tree		.30	.75
Thinnings		.60	1.50
Poisoning hardwoods			
3-inch and larger trees	3.00		3.00
6-inch and larger trees	2.00		2.50
Scarification	4.00		6.00
Release cutting			
600 trees per acre	3.80		3.00
300 trees per acre	2.50		2.00
Precommercial thinning	6.30		5.00
Planting	14.00		14.00
Pruning	11.00		9.00
Cruising and selling		.08	.30
General overhead		.02	.20[2]

[1]Includes supervision, materials, and depreciation on equipment.
[2]Annual costs.

the results have been checked with research foresters familiar with the area. They present reasonable estimates of the yield which might be obtained under the different levels of management in this area and are adequate for the use we will make of them in this study. These yield tables are presented in Tables 3 and 4, which show only the yields for the ages of the most profitable rotations.

The pine yields under all levels of management are based on the normal yield tables in *Volume, Yield and Stand Tables for Second Growth Southern Pines* (Office of For. Exp. Sta. *et al.*, 1929), using the loblolly pine tables for productivity classes 80 and 70 and the shortleaf pine tables for classes 60 and 50. The final yield under both Levels I and II management is entirely pine. For Level I, we assume the yield to be 80 percent of that shown in the normal yield table. Because of poorer stocking and fewer thinnings in Level II, its final yield is only 70 percent of that under Level I. Thinnings are assumed to remove 10 percent of the basal area and 25 percent of the trees present at the time of thinning under Level I and 20 percent of the basal area and 45 percent of the trees under Level II.

Under Levels III and IV management the stand will revert to hardwoods and only part of the final yield will be pine. We assume that one-third of the area will be occupied by pine and two-thirds by hardwoods and estimate the final yield of the pine as 20 percent under Level III and 10 percent under Level IV of the normal yield table volume. The hardwood portion of the final yield under these levels is based on Schnur's (1937) yield tables for upland oak forests. The hardwood yield under Level III is taken as 80 percent of normal and under Level IV is only 90 percent of the Level III yield.

An important factor is the increase in volume of the shelterwood stand and seed trees between the harvest cut and their final removal. These are large trees, selected for vigor, and can be expected to grow rapidly after release. We assume net rates of increase after mortality for these residual trees of 6 percent for Class 80, 5 percent for Class 70, 4 percent for Class 60, and 3 percent for Class 50.

Value yields. In estimating stumpage values we allow for the effect on price of the volume removed and assume that the full value differential due to size and quality of the sawtimber trees is realized in the sales. The pine yields by tree grade are estimated to be:

Level I: 75% Grade A, 25% Grade B
Level II: 25% Grade A, 75% Grade B
Levels III and IV: all Grade C
Thinnings: all Grade C.

Stumpage prices are extremely variable. The best averages available (Floyd and White, 1952; Cruikshank and Anderson, 1955), reduced somewhat to be conserva-

TABLE 3. Yield per acre from forest lands under high level management.

Productivity Class	Level I			Level II		
	Age	Final yield (bd. ft.)	Thinnings	Age	Final yield (bd. ft.)	Thinnings
	20		3 cds.	30		6 cds.
	25		3 cds.	35		
80	30		4 cds.	40		7 cds.
	35		4 cds.	45		
	40		2,000 b. f.	50		2,000 b. f.
	45	21,000		55	18,000	
	25		3 cds.	30		
	30		3 cds.	35		6 cds.
70	35		4 cds.	40		
	40		4 cds.	45		7 cds.
	45		2,000 b. f.	50		
	50		2,000 b. f.	55		2,000 b. f.
	55	19,000		60	15,000	
	30		3 cds.	35		
	35		4 cds.	40		
60	40		4 cds.	45		
	45		4 cds.	50		7 cds.
	50		2,000 b. f.	55		
	55		2,000 b. f.	60		7 cds.
	60	19,000		65	15,000	
	35		3 cds.	45		
	40		4 cds.	50		
50	45		4 cds.	55		8 cds.
	50		2,000 b. f.	60		
	55		2,000 b. f.	65		8 cds.
	60	12,000		70	11,000	

tive, have been used as follows:

Sawtimber per thousand board feet:

Grade A pine	$28.00
Grade B pine	25.00
Grade C pine	20.00
Hardwood	10.00

Pulpwood per standard cord:

Pine, clearcut	$3.00
Pine thinnings over 5 cds./ac.	2.00
Pine thinnings under 5 cds./ac.	1.00
Hardwood	2.00

The choice of rotations to be used. The amount of wood produced on an acre of land depends not only on the productive capacity of the land and the management practices applied, but also on the length of time the stand grows. The gross value product varies even more with the length of the growing period than does the physical product. We must therefore make a choice among the many production periods which we might use. Since we usually conceive of forestry as a sustained production process, this becomes a question of selecting the best production period to be used repeatedly into the indefinite future. This period is commonly called the "rotation."

When land is used in producing a valuable good, and the other factors used in this production (usually capital and labor) are paid at their best alternative rate, any difference between the value (selling price)

TABLE 4. Yield per acre from forest lands under low level management.

Productivity Class	Level III Age	Level III Pine (bd. ft.)	Level III Hardwood (bd. ft.)	Level IV Age	Level IV Pine (bd. ft.)	Level IV Hardwood (bd. ft.)
80	50	2,000	7,200	50	1,000	6,500
70	50	1,500	5,100	50	700	4,600
60	60	1,600	5,100	60	800	4,600
50	70	1,300	4,300	70	600	3,900

of the product and the cost of the services of the other factors is attributed to the services of the land and is called "economic rent." Under these conditions, land is being used most efficiently from an economic viewpoint when it is employed in a form of production which yields a maximum economic rent. Because in a sustained practice of forestry the outlays and receipts occur at various times, they can only be compared by moving them to a common point in time. The simplest way of doing this is to discount all costs and returns to the present time at an acceptable rate of interest. The difference between the present value of all future returns and the present value of all future costs other than for land is known as the "discounted economic rent" (Thomson, 1942). For any given parcel of land managed under any given set of practices, the discounted economic rent will vary with the length of the rotation used. The economically most efficient rotation to use on that parcel and under those practices is that which produces a maximum discounted economic rent.

The most efficient rotation was determined separately for each level of management on each productivity class of land. We assume that the land is already under management at the given level of intensity and that management will continue on a sustained basis into the indefinite future. All costs and revenues for the first rotation are carried forward at compound interest from the time they occur until the end of the rotation to give us accumulated costs and revenues as of the rotation end. We further assume that this same pattern will be repeated in subsequent rotations so that accumulated costs and revenues will be the same at the end of every rotation as at the end of the first. The present values of these accumulated costs and revenues are then obtained by discounting the permanent series of periodic revenues and costs which start one rotation length from the present. The difference between the present values of the future revenues and future costs is the discounted economic rent for the land under that level of management. The calculations were repeated for different rotation lengths until that rotation was found which gave the maximum discounted economic rent. Three percent was used in all compounding and discounting.

Since we assume the forest to be on a sustained operating basis, we must select some point in the rotation from which to start these calculations. A logical starting point appears to be immediately after the harvest cut. The value of the final yield itself is thus entered at the end of the rotation, but all costs start as of the beginning of the rotation. In levels I and II, the cost of scarification and hardwood poisoning is incurred in the year 0 and carried at interest for the full rotation length. The stumpage value of the shelterwood stands and seed trees left on the ground is entered as a cost at the beginning of the rotation and their sale value is entered as a revenue at the time of final removal. Gross values are entered for all costs and revenues and

carried to the end of the rotation in order to obtain the total costs and revenues involved. If it costs \$1.50 to mark for a thinning and the material removed sells for \$3.00, these figures are entered separately rather than the net realization of \$1.50. The reason for this will become clear in later sections. The most efficient rotation lengths are the ages shown for final yields in Tables 3 and 4. The discounted present values per acre of all future revenues and all future costs and the discounted economic rent per acre for the four management levels on the four land productivity classes are given in Table 5.

Comparative efficiency of levels of intensity. Table 5 shows that as the level of management intensity is raised on any productivity class, the amount of discounted economic rent increases. If land were the limiting factor of production, it would be most efficient to manage it as intensively as possible. Even the productivity classes which are submarginal for timber production at low intensity levels become supermarginal at higher levels.

The limiting factor, however, may be capital rather than land. Since high intensity levels require more capital than low, we may question whether high intensity will give the most efficient use of capital too. We can measure the efficiency of use of capital by the ratio of the discounted value of future revenues to the discounted value of future costs. The revenue figures for each level on each class in Table 5 were divided by the corresponding cost figures to give this index and are shown in Table 6.

We notice at once that on every productivity class the revenue–cost ratio increases as the level of management intensity is raised.[1] In other words, the more intensively forest land is used, the greater is the return per dollar invested in forest management. According to this, for efficient use of both land and capital a given piece of forest land should be managed as intensively as possible.

If we take this literally, it means that forest production on any given class of land is a decreasing cost process. Certainly this is true through the first three levels of intensity, because the quality of the stand deteriorates badly under the lower levels. At Level I, however, we added capital and labor in a lump consisting of a number of different operations. If we could separate these operations and determine

[1]The one exception is the decrease in the ratio from Level IV to Level III on Class 80, for which I can give no logical explanation.

TABLE 5. Discounted present values from forest management.

Management Level	Productivity Class 80	70	60	50
	Present Value of Future Revenues			
I	\$358.99	\$270.01	\$235.60	\$171.02
II	248.48	199.80	165.02	133.07
III	63.01	52.46	42.25	32.86
IV	25.12	17.73	12.67	7.37
	Present Value of Future Costs			
I	\$165.77	\$153.49	\$148.69	\$145.27
II	131.87	127.10	120.87	118.49
III	41.97	41.97	40.05	38.79
IV	15.09	15.09	15.06	15.04
	Discounted Economic Rent			
I	\$193.22	\$116.52	\$86.91	\$25.75
II	116.61	72.70	44.15	14.58
III	21.04	10.49	2.20	—5.93
IV	10.03	2.64	—2.38	—7.67

TABLE 6. Ratio of total revenues to total costs.

Management level	Productivity Class 80	70	60	50
I	2.17	1.76	1.58	1.18
margin	3.26	2.66	2.54	1.42
II	1.88	1.57	1.37	1.12
margin	2.06	1.73	1.52	1.26
III	1.50	1.25	1.06	0.85
margin	1.41	1.29	1.18	1.07
IV	1.66	1.17	0.84	0.49

how much each would increase total cost and total revenue if added one at a time in succession, the marginal revenue–cost ratio probably would reach a maximum and start to decline before all Level I operations were in effect. Unfortunately, we do not have the reliable forest management data to make this more–detailed analysis. Level I management includes only silvicultural operations which appear practical at present. There are other feasible operations, such as fertilizing the young trees, but these undoubtedly would be accompanied by diminishing returns. Forest production on all lands is not a decreasing cost industry because of the diminishing returns which accompany the use of poorer classes of land, as we will see in the next section. Still, our conclusion remains valid that if a given class of land can be managed only at Level II or Level I, it will be more efficient to manage it at Level I.

Comparative efficiency of productivity classes. Table 5 shows that at any given level of intensity, discounted economic rent decreases progressively from Class 80 to Class 50 land. The disparity between the economic rents on these extreme classes of productivity is striking. Under intensive management, one acre of Class 80 land has a value for timber production almost eight times as great as an acre of Class 50 land. The same pattern is shown in Table 6 by the revenue–cost ratios which decrease progressively from Class 80 to Class 50 at each level. A dollar invested in Level I management on Class 80 land produces an amount of revenue almost twice as great as it could on Class 50 land. Efficiency in the use of a given capital fund calls for its investment on Class 80 land if available, and if that is not possible, then on Classes 70, 60, or 50 in that order.

The least-cost expansion path for production. Forest production may be expanded either by adding more capital to the land already in use or by bringing new areas of land into use. If we wanted to expand production in the Region, how might we do it most efficiently?

As a starting point, let us assume that Class 80 land is under management at Level IV and no other forest land is being used. The efficiency of the use of capital here is shown by the revenue-cost ratio of 1.66 (Table 6). To expand production we must use additional capital. Suppose enough capital is available to raise the management intensity on the Class 80 land now in use to Level III. The efficiency of the use of this additional capital is shown by the marginal revenue–cost ratio of 1.41 in Table 6. (The marginal ratio is the ratio of the additional revenue which results from the use of added capital to the amount of capital which is added). When Level III is reached, the revenue–cost ratio for all capital in use at that level is 1.50.

The additional capital might instead be used to bring more land into production. If more Class 80 land is available, this capital could be used with it to yield a revenue–cost ratio of 1.66. It is obviously more efficient to bring more Class 80 land into production at Level IV than to raise the intensity to Level III on the land already in use. But suppose that all Class 80 land is already in use. The alternative, then, is to bring Class 70 land into use at Level IV. On Class 70 land the revenue–cost ratio for capital is only 1.17. In this case it is more efficient to use the additional capital to raise the Class 80 land to Level III and thereby obtain a ratio of 1.41.

With all Class 80 land in use, the efficient way to expand production is to raise intensity on this land to Level III. Now suppose that all Class 80 land is at Level III and we still desire further increased production. We can get this by intensifying use of the Class 80 land to Level II with a marginal ratio of 2.06. This is more efficient than bringing any other class of land into use. When one acre of Class 80 land has been raised to Level II, its use can be intensified still further to Level I with a marginal revenue–cost ratio of 3.26.

This clearly is a more efficient use of capital than would be raising a second acre from Level III to Level II (with a marginal ratio of only 2.06). Study of Table 6 shows that this same situation exists on all classes of land.

To make our analysis more realistic, we must concede that all forest land in the Region will be operated at a minimum intensity of Level IV, because when various classes of land are intermingled, adequate fire protection cannot be provided for some lands without protecting all. If the productivity classes were present in equal amounts, and all managed at Level IV, the average revenue–cost ratio for the capital used on these lands would be 1.04. The marginal ratio obtained by using capital to intensify the use of these lands to Level III varies from 1.41 on Class 80 land to 1.07 on Class 50. Intensifying the use of any of these lands thus shows a revenue greater than the cost involved. Class 50 land is still submarginal at Level III, but must operate at Level IV anyway, so is more efficiently managed at Level III. If all other classes were managed at maximum intensity it would be economical to raise Class 50 land from Level IV to Level III.

The least-cost expansion path for production, starting with all lands at Level IV, is as follows. First, intensify the use of each acre of Class 80 land to Level I before intensifying the use of any other acre. Second, when all Class 80 land is at Level I, intensify the use of each acre of Class 70 land to Level I before intensifying the use of any other acre. Third, repeat this procedure for Class 60 and finally for Class 50 lands.

We can base one final observation on Table 6. If the conditions existed which we have assumed—that is, if there were no limit on the amount of labor and capital which could be used and no limit on the product which could be sold—it would be economical to intensify the use of all forest lands in the Region to Level I.

Application to the region. The relative amounts of the different productivity classes present in the study area, as determined by a brief field survey, are as follows:

Class 80	110,000 acres	15%
70	300,000	40
60	260,000	35
50	80,000	10
	750,000	100

If the different levels of management intensity were applied to all of the forest lands in the Region the results would be as shown in Table 7. The value of the Region's lands for forest production, as measured by the discounted economic rent, would be more than one hundred times greater with intensity Level I management than with Level IV. Level I management would produce gross revenues for the Region sixteen times what they would be under Level IV management. This larger gross revenue would be obtained with costs only ten times higher than those at Level IV. The same point is brought out by the revenue-cost ratios. Under Level IV management, the revenues produced represent a yield on the capital invested of just slightly more than its three percent alternative rate. By contrast, under Level I management, the gross revenues produced amount

TABLE 7. Financial results of regional forest land management.

Management Level	Present Discounted Values			Revenue-cost Ratio
	Revenues	Costs	Economic Rent	
I	$195,389,500	$114,562,700	$80,826,800	1.71
II	140,823,600	93,541,000	47,282,500	1.51
III	36,282,900	30,723,900	5,559,000	1.18
IV	11,966,000	11,305,700	660,300	1.06

to 1.71 times the expenditures (including three percent interest on all capital invested). Under the simple assumptions made thus far, the best Regional policy would be to manage all forest lands at a Level I intensity.

The Influence of Present Forest Condition on Land Use

In the preceding section we started our analysis from the assumption that the land was already under management at a given intensity level. We now must relax this assumption and recognize the fact that most forest lands in the study area are not being managed at all. The policy of landowners up till now has been to leave their forest lands alone except when they wished to sell some products or cut some for their own use. As a result, there is great variation in the present condition of forest stands in the area. Before these lands can be placed under permanent management on any desired long-run level, they must pass through a period of adjustment while their condition is brought up to the desired level. We will start this part of our analysis with the forest stands as they now are and study the results of converting these existing stands to forests managed at the various levels of intensity. For the present we will continue to ignore problems of ownership and assume perfect competition in the markets for labor and capital and for the products grown.

The present forest condition classes. Since our analysis is limited to the potential pine lands in the Region and to the objective of producing pine as a final crop, we will classify present condition according to factors which affect this objective. Much of the present forest land was at one time cleared and cultivated. When cultivation was abandoned, this land seeded in naturally to pine. As these pine stands grew older they gradually opened up due to losses from fire, storms, insects, and disease. Hardwood species then invaded the stand and established an understory. When the pine timber was cut—either completely or partially—the hardwoods were released and grew into the overstory. Subsequent cuttings gradually removed the pines and the stand became almost, if not entirely, pure hardwood. The present forests in the region represent all stages in this progress from pure pine to pure hardwood. How difficult it is to get a present stand into condition for long-run management depends on which stage it now is in. Long–run management can start immediately on pure pine stands. But if land supporting pure hardwoods is to be managed for pine, the hardwoods must be removed and the stand converted to pine.

The age of the stand is not important at this stage in our analysis. In pure pine stands, age affects only the time at which the stand can be harvested and long–run management put into full effect. In hardwoods, the present stand has to be removed and replaced by pine regardless of its age. We therefore divide present condition into only four classes: two pine and two hardwood. A stand is classified as pine if 75 percent or more of the volume is pine and as hardwood if 75 percent or more of the volume is hardwood.[2] Pine stands are further divided on the basis of present stocking and hardwood stands on the basis of whether the present stand shows prospects of producing a merchantable hardwood crop. The classes used in the study are as follows:

Class A: well-stocked pine stands
Class B: understocked pines stands
Class C: well-stocked hardwood stands of good species
Class D: miscellaneous poor hardwood stands consisting of culls, poor species, and cutover sprout stands

Required silviculture for present stands. In our model Class A stands are immediately put under long-run management. For

[2]Few stands were found with intermediate mixtures and these were placed in the category which they most closely resembled.

Level IV, they are carried to rotation age and clearcut. For Level III, they are carried to rotation age and cut by the seed tree method. For Levels I and II, the cultural work at the corresponding age is applied and continued according to the requirements of that level.

Class B stands are also immediately put under long-run management. Since they are understocked, the first thinnings are omitted under Level I.

Class C stands present two possibilities for management at Levels I and II. It is possible either to clear the hardwoods immediately and plant to pines or to carry the present hardwood stand to merchantable size, harvest it commercially, and then plant to pines. We will test both possibilities. For Level I management under choice 1, the large hardwoods are poisoned and the small hardwoods cut. The area is then scarified or burned and 1000 pine seedlings planted per acre. These are released at two years and again at five years. Under choice 2, the procedure is the same except that only the remnant hardwoods need be poisoned after the mature hardwood stand is harvested. For Level II management, the procedure is the same as for Level I except that only 500 seedlings are planted per acre and these are released only once, at three years. In both cases, after the release of the pines the cultural methods of the level in question are applied as on a long-run basis. Level III management cannot be applied to Class C stands since pine seed trees are not available. Under Level IV management the stands are carried to maturity and clearcut.

Class D stands are cleared immediately for Levels I and II management. The hardwoods are poisoned and the area scarified or burned. Planting and release is then done under the same specifications as on the Class C stands. Level III management cannot be applied to Class D stands because of the lack of pine seed trees. For Level IV the stands are carried to maturity and clearcut.

TABLE 8. Costs of placing present stands under management.

Management level	Cost Item	Cost (per acre)
	CLASS A	
I	Omit costs up to precommercial thinning in first rotation	
II	Omit costs up to thinnings in first rotation	
III	Taxes and protection only in first rotation	
IV	Same as long-run throughout	
	CLASS B	
I	Omit costs up to pruning in first rotation	
II	Omit costs up to thinnings in first rotation	
III	Taxes and protection only in first rotation	
IV	Same as long-run throughout	
	CLASS C (holding hardwoods for one rotation)	
I	First rotation costs same as for Level IV	
	Poison remnant hardwoods	$ 5.00
	Scarify or burn area	5.00
	Plant 1000 trees per acre	16.50
	Release cutting at 2 years	3.00
	Release cutting at 5 years	3.00
	Thereafter, same as long run	
II	Same as for Level I, except:	
	Plant 500 trees per acre	9.00
	Release cutting at 3 years	2.00
IV	Same as long-run but rotation 10 years longer	
	CLASS C (clearing hardwoods immediately)	
I	Poison large hardwoods	$ 5.00
	Cut small hardwoods	3.00
	Scarify or burn area	6.00
	Plant 1000 trees per acre	16.50
	Release cutting at 2 years	3.00
	Release cutting at 5 years	3.00
	Thereafter, same as long-run	
II	Same as for Level I, except:	
	Plant 500 trees per acre	9.00
	Release cutting at 3 years	2.00
	CLASS D	
I	Poison and cut hardwoods	$ 5.00
	Scarify or burn area	5.00
	Plant 1000 trees per acre	16.50
	Release cutting at 2 years	3.00
	Release cutting at 5 years	3.00
	Thereafter, same as long-run	
II	Same as for Level I, except:	
	Plant 500 trees per acre	9.00
	Release cutting at 3 years	2.00
IV	Same as long-run but rotation 10 years longer	

The costs of management. The costs of placing existing stands under management may differ from the long–run costs we previously used in three respects: (1) the cost of first establishment may not be necessary because the stand is already satisfactorily established, as in Classes A and B; (2) the cost of first establishment may be higher because the existing undesirable stand has to be replaced, as in Classes C and D under Levels I and II; (3) the rotation may have to be lengthened because the stand is all hardwood. Table 8 gives the costs of establishing the various levels of management on the different condition classes. These costs are higher for some operations than those we used before because of the difficult conditions faced in the primary conversion from hardwood to pine.

The yield under management. When we put an existing stand under management there will be a period during which the forest adjusts to long–run conditions. The yield at the end of the first rotation will depend on the present condition of the stand and the level of management applied to it. The full long-run yield should be reached at the end of the first rotation on Class A stands under Levels I or II. It should be reached at the same time if these levels are applied to Class C and D stands through immediate clearing and planting. Class B stands will fall short of the long–run yield in the first rotation under Levels I and II because of understocking. Both Classes A and B will show higher than long–run yields in the first rotation under Levels III and IV because the first crop will be almost entirely pine. Class C and D stands under Level IV will have yields made up entirely of hardwoods, instead of pine and hardwood, and will require longer rotations than under long–run. The yields from all condition classes under management are given in Table 9.

Results of management of the present condition classes. We analyze the results of management in the same manner as before—present discounted values of all future revenues and costs are obtained. The same rotations are used as in the long–run analysis, with the exception of the hardwoods noted above. A full first rotation is used in each case; that is, the accumulating of costs and revenues starts with the year 0, though in the first rotation the stand is accepted as having been established naturally at no cost. Table 8 shows the cost pattern for the first rotation. The stands reach a sustained operating basis at the end

TABLE 9. Yield from present stands under management.

Management level	Yield
	CLASS A
I	Same as long run throughout
II	Same as long run throughout
III	First rotation: 80% of Level II yield priced at $25; second rotation: 70% of first rotation; thereafter: same as long-run
IV	First rotation: same as Level III; second rotation: Level IV yield but half pine at $20 and half hardwood at $10; thereafter: same as long-run
	CLASS B
I	First rotation: 70% of long-run; thereafter: same as long-run
II	First rotation: 70% of long-run; thereafter: same as long-run
III	First rotation: 70% of Level II yield priced at $20; thereafter: same as long-run
IV	First rotation: same as Level III; thereafter: same as long-run
	CLASS C (holding hardwoods for one rotation)
I	First rotation: same as for Level IV; thereafter: same as long-run for Level I
II	Same as Level I, except Level II long-run yields thereafter
IV	Same as long-run throughout, but all hardwood
	CLASS C (clearing hardwoods immediately)
I	Same as long-run throughout
II	Same as long-run throughout
	CLASS D
I	Same as long-run throughout
II	Same as long-run throughout
IV	Hardwood portion only of the long-run yield for this Level throughout

of either the first or second rotation, and subsequent results are handled as permanent periodic revenues and costs.

Let us first compare the two possible ways of handling the Class C stands under Levels I and II. Both the discounted economic rent and the revenue–cost ratio prove to be higher when these stands are cleared immediately and planted to pines than when the existing hardwoods are carried to maturity, harvested, and the land then cleared and planted. For example, under Level I management on Class 80 land, the discounted economic rent from immediate clearing and planting is $156.10 as compared to $31.47 from holding the hardwoods one rotation. The revenue–cost ratio is 2.44 as compared to 2.05. This is true because the value of a fully–stocked pine yield at the end of the first rotation is so much greater than the value which hardwoods naturally produce, that it more than outweighs the cost of immediate conversion to pine. This same relationship is found on all productivity classes at both Levels I and II, so we will consider immediate clearing and planting as the proper management for these levels on Class C stands.

The discounted economic rents resulting from the application of the four management levels to the various condition classes on the four land productivity classes are presented in Table 10. The ratios of the present discounted values of all future revenues to all future costs are presented in Table 11.

In Table 10 we see that discounted economic rent under management shows the same pattern for all present stands as it did in the long–run analysis. It increases progressively with increasing intensity of management on every productivity class and also from Class 50 to Class 80 under every level of management. The comparison between condition classes is what we might expect. Economic rent is highest on Class A because the fully–stocked pine stand does not require any establishment cost in the first rotation. It is second highest on Class B on the poorer productivity classes and under Level IV for the same reason. However, on the better productivity classes under Levels I and II the full stocking obtained by planting the Class C and D lands outweighs the cost and both Classes C and D on Class 80 and Class D on Class 70 show higher economic rent than Class B. Class C stands on productivity Class 50 land are submarginal at every management level.

TABLE 10. Discounted economic rent from applying management to present stands.

Management level	Productivity Class 80	70	60	50
		Condition Class A		
I	$192.98	$120.63	$95.20	$38.10
II	113.63	73.93	49.45	23.62
III	71.95	50.00	34.84	15.24
IV	65.06	44.71	31.76	13.94
		Condition Class B		
I	$144.62	$85.16	$64.91	$21.96
II	80.76	49.67	30.82	11.24
III	44.25	29.07	18.76	5.56
IV	41.73	27.28	17.98	5.34
		Condition Class C		
I	$156.10	$83.75	$58.42	$—0.90
II	87.77	48.07	23.58	—2.24
IV	4.97	0.07	—5.21	—9.12
		Condition Class D		
I	$161.10	$88.75	$63.42	$6.32
II	92.77	53.07	28.31	2.76
IV	2.52	—1.77	—6.66	—9.84

Table 11 shows a familiar pattern on the Class C and D stands. The revenue–cost ratio increases progressively with increasing intensity of management. On these classes the investment will be recovered only on the Class 80 land under Level IV. On Class 50 lands, the investment will not be recovered on Class C stands and will just barely be recovered on Class D stands

TABLE 11. Ratios of discounted revenues to discounted costs for present stands under management.

Management level	Productivity Class 80	70	60	50
	Condition Class A			
I	3.69	3.03	2.74	1.74
II	3.53	2.81	2.34	1.69
III	4.39	3.35	2.80	1.84
IV	5.31	3.96	3.11	1.93
	Condition Class B			
I	3.13	2.53	2.27	1.45
II	2.80	2.22	1.84	1.33
III	3.09	2.37	1.97	1.31
IV	3.77	2.81	2.19	1.36
	Condition Class C			
I	2.44	1.87	1.64	0.99
II	2.24	1.72	1.38	0.96
IV	1.33	1.00	0.65	0.39
	Condition Class D			
I	2.56	1.97	1.73	1.08
II	2.41	1.86	1.49	1.05
IV	1.17	0.88	0.56	0.35

at the higher management levels. The revenue–cost ratio pattern is different on the Class A and B stands. Here the ratio is highest under Level IV, decreases to Level II, and then rises again under Level I management. The reason for this lies in the high pine yields obtained in the first rotations at the lower intensity levels (because of the existing pine stands which do not involve any cost of establishment) and the low management costs at these levels.

Comparison with long–run efficiency. We can best see the effect of present condition of forest stands on the efficient use of forest land by comparing the results of the present condition analysis (Tables 10 and 11) with those obtained in the long–run efficiency analysis (Tables 5 and 6).

Class A stands show discounted economic rents which are higher than under long–run efficiency at all levels of management on all productivity classes, except Levels I and II on Class 80.[3] No Class A stand shows negative economic rent at any level of management. The efficiency in the use of capital, as measured by the revenue–cost ratio, is higher in all cases than under long–run. This is because there is no cost of establishment in the first rotation. What really happens is that the operation starts with a growing stock for which no capital charge need be entered in the calculations. This class of stand is by far the most efficient with which to start management.

Class B stands show discounted economic rents which are lower than under long–run efficiency at Levels I and II, but higher at Levels III and IV. No Class B stand shows negative economic rent. The revenue–cost ratios are higher in all cases than under long–run. The use of capital is more efficient because no costs of establishment are required for the first rotation. Because Class B stands are understocked, their yield in the first rotation is less than long–run at Levels I and II but is still greater than long–run would be at Levels III and IV. When efficiency in the use of capital is considered, Class B stands are the second most efficient with which to start management.

Class C and D stands show lower discounted economic rents under all conditions than those obtained under long–run efficiency. This is because of the high initial cost of clearing and planting under Levels I and II, and because there is no pine in the stand at Levels III and IV. Class C stands are submarginal on productivity Class 50 under Levels I and II and Class D is submarginal under Level IV on Class 70 land although these classes are supermarginal at these levels on the long–run basis. Classes C and D are poorest in return per acre but in use of capital these classes are more efficient than long–run under Levels

[3]The exception on Class 80 is due to the rapid rate of value increase on the shelterwood stand at the beginning of the first rotation under the long-run analysis.

I and II on all productivity classes except Class 50. This is because less captial is used in the first rotation, since there is no investment in a shelterwood stand.

The least–cost expansion path for production. Let us now again assume that all forest land in the area is managed at a minimum intensity of Level IV and that we desire to expand production by using additional amounts of capital with the given amount of land. Where and how should we use this capital for the greatest efficiency? The answer can be found in Table 12, which shows the marginal return–cost ratios which result from changing the management intensity on the various condition and productivity classes.

If only Class A and B stands are available we find, as under the long–run analysis, that it is most efficient to first raise the Class A stand on Class 80 land to Level I and then proceed down the range of productivity classes, raising each Class A stand to Level I before proceeding to the next. When all Class A stands are managed at Level I, we should follow the same course with the Class B stands. (For certain amounts of desired total production, we might find it more efficient to intensify the use of Class B stands on Class 80 and 70 land before intensifying the use of Class A stands on Class 50 land.)

Class C and D stands do, however, exist. If we intensify their use, it must be from Level IV to II because they contain no pine seed trees which would permit the use of Level III. If we can make this jump in intensity, we can get a higher revenue–cost ratio by intensifying the use of Class D stands on Class 80 and 70 land and Class C stands on Class 80 land than by more intensive use of Class A and B stands. This makes the decision on how to expand production in the region rather involved. In general, we can say that it is best to avoid the Class 50 land altogether and to expand use first on the Class A stands. Next we should increase intensity on some of the Class C and D stands, then the Class B, and finally the remainder of the Class C and D.

TABLE 12. Marginal revenue–cost ratios under management.

Management Level	Productivity Class 80	70	60	50
	Condition Class A			
II– I	3.96	3.52	3.58	1.87
III– II	2.77	2.22	1.83	1.51
IV–III	2.12	1.86	1.72	1.43
	Condition Class B			
II– I	3.76	3.37	3.39	1.76
III– II	2.55	2.05	1.69	1.35
IV–III	1.41	1.29	1.18	1.07
	Condition Class C			
II– I	2.80	2.21	2.22	1.04
IV– II	2.49	1.93	1.60	1.15
	Condition Class D			
II– I	2.80	2.21	2.24	1.13
IV– II	2.78	2.18	1.81	1.31

Application to the region. The relative areas of the different present condition and productivity classes present in the study area are shown in Table 13. The bulk of the Region's forest stands, 29 and 49 percent respectively by area, fall in Classes A and B. Large areas of these more efficient forest stands are available for management. Over 60 percent of the Class C and D stands are on the two poorest classes of land and only 10 percent on the most productive land. This simplifies our choice of the stands to manage intensively. Unless more stands are allowed to deteriorate to Class C and D condition, this kind of forest should be only a minor management problem in the Region.

The Influence of Ownership on Forest Land Use

Up to this point we have conducted our analysis as though all forest lands in the region were under one central administration which could adjust the intensity of use of different lands in accordance only with

TABLE 13. Classification of forest land in the region by productivity and present condition.[1]

Condition Class	Productivity Class 80	70	60	50	Totals
A	43,000	88,000	78,000	9,000	218,000
B	51,000	166,000	113,000	35,000	365,000
C	8,000	27,000	43,000	18,000	96,000
D	8,000	19,000	26,000	18,000	71,000
Totals	110,000	300,000	260,000	80,000	750,000

[1]Area in acres.

TABLE 14. Classes of farm ownership.

Class of Farm	Size of farm (acres) Range	Average	Forest land on farm Acres per farm	Percent of farm area
Small	0– 99	50	19	38
Medium	100–199	140	60	43
Large	200–499	310	135	44
Very Large	500+	720	370	51

their productivity and the condition of the forest stands on them. But these forest lands are in fact controlled by numerous owners, each having only a small part of the total forest area. So we will now relax most of our previous assumptions and recognize that institutional problems of ownership exist and that the markets for productive factors and forest products are not perfect. For the time being we will still retain two broad assumptions: that all forest land in the region is available for forest production, and that the market will absorb any total amount of regional production at prevailing prices.

The ownership classes. Private ownership is paramount in the study area, less than one percent of the total land being publicly–owned. These private holdings fall logically into two major groups: farm and non–farm. I have further subdivided the farms, which contain the bulk of the forest land in the Region, into four classes based on size, as shown in Table 14. There is virtually no information on the non–farm properties, except that most of them are fairly large. So we will assume that the average size of woodland on the non–farm holdings is the same as on the Very Large farms.

Effect of type of owner on land use. We will classify ownership here on the basis of use. The ownership of land in an operating farm is classified as farm ownership regardless of whether the owner actually is a farmer or not. The non–farm classification includes only land which is not part of an operating farm enterprise. The owner does, however, influence the use of his land, whether it be farm or non–farm. A recent study of private forest landownership in Central Mississippi (James *et al.*, 1951) found that non–farmer owners were divided fairly equally between wood–using industries and a miscellaneous group of business men, housewives, wage earners, and professional workers. The general pattern in the Georgia Piedmont is probably about the same.

Availability of labor. The most common farm types in the study area are livestock farms and cotton and general farms. The livestock farms provide full year–round employment for their labor, and most, if not all, forestry work on these farms must be done with hired labor. By contrast, on the cotton and general farms there are about two months a year when the farm labor force is not occupied with farm operations. In 1950, 40 percent of the farm operators in the Region worked some time off their farms and 24 percent of them worked off the farm more than one hundred days a year (Census, 1952). There is a sufficient labor force for forestry work on the cotton and general farms, and since these are most numerous in the area part of this labor should also be available for forestry work on livestock farms and non–farm properties. Whether this labor is actually employed in forestry will depend on how forestry wages compare with those

paid in the other occupations which are becoming more numerous each year.

Ability to wait. Since the returns from current silvicultural work will not be realized for many years, an owner's willingness to invest in forestry is bound to be influenced by the length of time he expects to retain ownership. Farm ownership in Georgia is quite stable, the rate of ownership transfers being among the lowest in the country. The stability of ownership among the non–farmer owners is probably also rather high, since most of them consider forest land an investment rather than a speculation. Most of the owners in the Region, therefore, are able to take a long–range view.

Supervision and control. Management of forest lands at the higher levels of intensity requires that many operations be done at the right time and in the right manner. This is not possible unless the owner can keep in touch with his property and control what is done on it. In 1950 only 14 percent of the farm units in the study area were operated by tenants (Census, 1952).[4] Ninety–six percent of the farm operators actually reside on the farm they operate. In addition, many tenants are quite stable and stay on one farm for a long time. Adequate supervision and control should be available for the management of most of these farm woodlands. Furthermore, it appears that most of the owners of tenant–operated farms and non–farm property are local residents—living in the small towns or adjacent cities—and not the type usually thought of as "absentee owners."

[4]The Census reports that 43 percent of the "farms" in the study area are tenant operated, but under Census definition a few acres of cotton operated by a cropper is counted as a "farm." A single operating farm unit may have many croppers working parts of it. For forestry, the farm unit is what counts. The census figures were adjusted to get the number of operating units and 14 percent of these were found to be operated by tenants.

Need for education and assistance. In general, the types of owners found in the Region are favorably situated to manage their forest lands. But they are not familiar with the practice of forestry. In order to operate their forest lands at the higher levels of intensity, they need technical assistance on such work as marking for cuttings and continuing education and advice on general problems of forest management. This assistance and advice may be hired by the landowner from forestry consultants or may be furnished free, or at a nominal charge, by a public agency. The cost of technical labor for necessary silvicultural operations was included in the calculation of long–run efficiency. From the regional viewpoint, the cost of education and advice —whether obtained from private or public sources—is an additional cost of managing these privately–owned lands.

Effect of size of holding on land use. We have seen that the type of owner found in this Region is not a real obstacle to forest management. There is, however, another aspect of ownership which we must consider: the size of holding.

Cost of forest production. There do not seem to be any reasons why forest production costs should differ with size of ownership in this Region. Even the Very Large class of ownership is not large enough to provide a full–time forestry enterprise. The benefits of increased specialization and efficiency which might exist in a really large forestry enterprise are not possible here.

One class of cost, however, does vary with size of ownership: the cost of education and advice. These must be supplied on an individual basis to each owner and the time required to encourage and advise him depends more on his personality than on the acreage he owns. For this study we will assume that the cost of education and advice (not including service work such as marking) varies directly with the number of owners and not with the area involved. The cost per *ownership* will be the same

for all, but the cost per *acre* will vary with the size of ownership.

The type of education and advice we are thinking of here is similar to that provided by county agricultural agents. For a successful sustained program of intensive forest management, the "forestry agent" should see each of his clients at least once a year. With allowance for all the vicissitudes of such a job, he should see an average of two owners a day, which would give him a possible clientele of 500 owners. Since this "forestry agent" must be a man of some caliber, his salary, travel, and expenses might amount to $6,000 per year. Education and advice would then cost 12 dollars per year for each owner, and this capitalized at three percent gives a present value for the service of $400 per ownership. The discounted cost per acre for the various ownership classes is as follows:

Small farm	$21.05
Medium farm	6.67
Large farm	2.96
Very large farm	1.08
Non-farm	1.08

This discounted cost must be subtracted from the discounted economic rent for any particular acre to determine the value of that land for forest production from a regional viewpoint. Education and advice are needed only when land is managed at Levels I or II. Referring to Table 10, we see that with this additional cost some other classes of land become submarginal for forest production at these levels. On Large farms, Class D stands on Class 50 land are submarginal at Level II. On Medium farms Class D stands are submarginal at all levels on Class 50 land. From a regional viewpoint, this necessary additional cost rules out intensive management of Class 50 lands on the smaller landholdings, except where the present condition class is very favorable.

The cost of education and advice also affects the efficiency of capital use. Since it is an additional cost without any additional revenue, the general effect is to reduce the revenue–cost ratio by some amount, depending on the size of ownership involved. This can be seen by comparing Table 15 with Table 11. Table 15 shows ratios only for Level I management on Class A stands, but the same pattern occurs under Level II and on other condition classes. The decrease in efficiency is small on Very Large farms; the ratio drops only from 3.69 to 3.63 on Class 80 land. The smaller the property, the greater the decrease in efficiency; for Small farms it drops from 3.69 to 2.85 on Class 80. If small farms are to use capital as efficiently as large farms, they must have more productive land. For example, capital can be used more efficiently on Class 70 land on Very Large and Large farms than on Class 80 land on Small farms. We may summarize this by a general statement that from a regional viewpoint it is more efficient to produce timber on large ownerships than on small.

TABLE 15. Revenue–cost ratios for level I management of class A stands.

Ownership Class	Productivity Class 80	70	60	50
Very large	3.63	2.98	2.69	1.71
Large	3.55	2.89	2.60	1.65
Medium	3.38	2.72	2.45	1.54
Small	2.85	2.24	1.98	1.24

Incentive to management. The interest which a private landowner takes in managing his forest land depends to a large extent on the income he expects to receive from it. What incentive might there be for the owners in the Region to manage their lands? For comparative purposes, let us assume that each property contains only one productivity class of land which is all managed at the same level on a sustained yield basis. Then the annual incomes in Table 16 are what an owner might expect from his forest lands. This table shows net annual incomes—that is, the difference between current income and current costs

Since no charge for capital is included, these net incomes represent return to both investment and entrepreneurship from managing forest land. (The cost of education and advice is also omitted in Table 16.)

The annual income from forest lands on the Small farms is very low, even with Level I management and the most productive lands. Even on Medium farms, income is low on the less productive lands. These owners can add something to their total income by managing their forest lands. If they do the work themselves in what otherwise would be idle time, their labor has no alternative cost and actual income will be slightly larger than shown in Table 16. But the potential increase in income is hardly enough to stimulate small farm owners to change their present pattern of management. On the larger farm and non–farm properties, potential returns should be large enough to interest owners in exploiting this additional source of income.

Marketing the crop. The most serious market imperfection in the Region is that timber usually cannot be sold in amounts smaller than some minimum quantity set by the buyers. Most portable sawmill operators feel they cannot afford to move into a tract and set up a mill to cut less than 100 thousand board feet. Pulpwood producers also need some minimum quantity to justify moving into a new tract. If a property is located close to a stationary sawmill or to a pulpwood landing on a railroad, smaller quantities may be purchased or the landowner may be able to log his own timber and haul it to the mill or landing. But as a general rule small quantities of timber cannot be marketed in the study area today.

The significance of this becomes clear if we look at the potential annual sustained yields under Level I management shown in Table 17. Even with the most intensive management, only the Very Large ownerships can produce enough to make annual sales. (With lower level management, annual yields would be still smaller.) The other ownership classes cannot operate on an annual sustained yield basis simply because they could not sell the small annual product. They can cut only periodically if they are to cover enough area to produce a salable volume. For the Small owner and the larger owners with low–productivity lands this means long intervals between sales. A Small owner can make a cutting only every 10 years if he has Class 80 land and only every 25 years if he has Class 50 land. This alone may eliminate any incentive to practice intensive management.

TABLE 16. Net annual incomes under sustained yield forest management.[1]

Management level	Productivity Class 80	70	60	50
	Average Income Per Acre			
I	$ 13.12	$ 10.23	$ 9.26	$ 4.73
II	9.19	7.01	5.74	3.84
III	1.90	1.26	0.99	0.69
IV	1.24	0.74	0.58	0.28
	Total Income on Very Large Farms and Non-Farm Ownerships			
I	$4,854.40	$3,785.10	$3,426.20	$1,750.10
II	3,400.30	2,593.70	2,123.80	1,420.80
III	703.00	466.20	366.30	255.30
IV	458.80	273.80	214.60	103.60
	Total Income on Large Farms			
I	$1,771.20	$1,381.05	$1,250.10	$ 638.55
II	1,240.65	946.35	774.90	518.40
III	256.50	170.10	133.65	93.15
IV	167.40	99.90	78.30	37.80
	Total Income on Medium Farms			
I	$ 787.20	$ 613.80	$ 555.60	$ 283.80
II	551.40	420.60	344.40	230.40
III	114.00	75.60	59.40	41.40
IV	74.40	44.40	34.80	16.80
	Total Income on Small Farms			
I	$ 249.28	$ 194.37	$ 175.94	$ 89.87
II	174.61	133.19	109.06	72.96
III	36.10	23.94	18.81	13.11
IV	23.56	14.06	11.02	5.32

[1]Return to both investment and entrepreneurship.

Application to the Region. Table 18 shows the distribution of forest land among the various ownership classes and the number of owners involved. Small farm owners possess a minor part of the Region's forest

TABLE 17. Annual sustained yields under level I management.

Ownership Class	Productivity Class 80	70	60	50
	Sawtimber (thousand board feet)			
Very large	196	159	144	78
Large	72	58	53	28
Medium	32	26	23	13
Small	10	8	7	4
	Pulpwood (cords)			
Very large	115	93	93	111
Large	42	34	34	41
Medium	19	15	15	18
Small	6	5	5	6

TABLE 18. Ownership of forest land in the region.

Ownership	Forest Land Area in Acres	Percent	Number of Owners
Non-farm	146,250	19.5	395
Very large	183,000	24.4	495
Large	174,000	23.2	1,017
Medium	137,250	18.3	2,288
Small	109,500	14.6	5,783
Totals	750,000	100.0	9,958

land. The two smallest classes own only one–third of the forest land, while the two largest classes own almost half. Furthermore, most of the owners are in the classes having the smallest properties. We will see the significance of this later.

External Influences on Forest Land Use in the Region

We have treated the Region thus far as an independent unit and have considered only conditions within the Region itself when determining the efficiency of forest land use. This is obviously not realistic. For the Region is not a self–contained economic unity; it is only part of a larger sphere of economic activity and quite dependent on exchange with the surrounding world. What happens outside the Region influences materially what is, or can be, done within. We will now consider those changes in the external economic environment which are most likely to influence forest land use in the Region and explore the possible effects of such changes. For the time being we will treat these external influences only subjectively, but later we will try to fit the Region objectively into the total economic picture.

Changes in the consumption of forest products. The most important forest products grown in the Region are sawtimber and pulpwood. Other products make up only a small part of the total wood production, and changes in their consumption will have little effect on the Region. At present, the cubic volume of wood removed as sawlogs is more than twice that removed as pulpwood. Pulpwood production, however, almost trebled in the Region between 1946 and 1954 (Cruikshank, 1947; Stover and Christopher, 1955). According to recent estimates, nationwide consumption of lumber will increase only 8 to 11 percent while pulpwood consumption will increase 58 to 79 percent between 1952 and 1975 (Rettie, 1955; Stanford Research Institute, 1954). This means a change in the relative demand for these two important products in the future. The present demand for forest products exists in a period of high economic activity, and the 1975 estimates assume that this condition will continue. We have no assurance, however, that the cyclic pattern which has characterized past business behavior will not continue, and future demand actually may be below present levels, at least for periods of time. Shifts in the relative consumption of sawlogs and pulpwood and fluctuations in total demand for these products will both be reflected in the prices for which Regional wood products can be sold. What effect would changes in the prices of two major products have on efficient forest land use?

With present stumpage prices of $3.00 per cord for pulpwood and $20.00 to $27.00 per thousand for sawtimber, it is more efficient to produce sawtimber than pulpwood on any class of forest land. In fact, Class 50 land is submarginal for pulpwood growing even under Level I management, and still would be at twice the present price of pulpwood. If the price of pulpwood trebled—to $9.00 per cord—sawtimber production at present prices would still be most profitable. This means that a tremendous change would have to occur in relative prices before it became more efficient to grow pulpwood than sawtimber as the major crop. Since a large amount of pulpwood will be produced from thinnings under high level management for sawtimber and much of the resulting mill and logging residues will be pulped in the future (Todd, 1955), it hardly seems possible that such a shift in relative prices will occur.

A change in the stumpage price of sawtimber will not affect the relative efficiency of the various levels of management or of the use of the different condition and productivity classes. It will cause some shifts in the classes which are supermarginal or submarginal for timber production, as we can see from the discounted economic rents in Table 5. Average pine stumpage prices in the Georgia Piedmont increased from $12.50 per thousand in 1949 to a high of $21.75 in 1952. (Floyd and White, 1949; same, 1952). A drop back to 1949 prices would mean a 43 percent decrease in price. Cruikshank and Anderson (1955) report an actual price decrease of 24 percent between 1952 and 1954 in South Carolina. The only currently supermarginal class under the higher levels of management which a price fall as large as 43 percent would make submarginal is Class 50 land under Level II management. Under Level I management, Class 50 land would still be supermarginal for timber production even at 1949 prices. Smaller price decreases would make some classes submarginal under the lower levels of management. A 20 percent drop makes Class 60 submarginal under Level III and Class 70 under Level IV, but these are inefficient levels of management anyway.

Should prosperous economic conditions continue, a further increase in stumpage prices is conceivable. The changes wrought by such a price rise would also be slight. Increasing price by 20 percent changes to supermarginal only the presently submarginal Class 50 under Level III and Class 60 under Level IV; Class 50 under Level IV stays submarginal. No foreseeable change in the consumption of forest products will affect the conclusions we have already reached as to efficient forest land use in the Region.

Changes in the availability of labor. Labor is essential in forest production even though the amount required per unit of product is small. The Southeast has witnessed a marked migration from rural to urban areas during the past decade. This and the increase in other local employment have caused a growing scarcity of agricultural labor. This scarcity is largely due to the higher wages paid by other employers. If forest land management can pay wages equivalent to or higher than those in other employment, it should be able to obtain labor.

In our previous analysis we have used a wage rate of 75 cents per hour. This was the legal minimum but was exceeded in many types of employment in the Region. If we increase the wage rate to the new $1.00 minimum, the effect is to reduce the discounted economic rent. The amount of the reduction varies with the level of management and the class of land involved. However, the reduction is not large—from 4 percent on Class 80 to 28 percent on Class 50 under Level I—and in no case does it make land submarginal which was not already so. It may be argued that $1.00 is too low a wage to use on any long-

run basis. If we double our original wage rate to $1.50 per hour, discounted economic rent is further reduced, but still no presently supermarginal class of land becomes submarginal. We may conclude that forest production in the Region can pay wages much higher than current rates without becoming unprofitable.

Changes in investment opportunities. The most important productive factor in forestry is capital. Whether the necessary capital will be available for forest production will depend on what it can earn in other investments in the Region. We have used an interest rate of three percent as a reasonable return for long–term investments. Without question, other investments in the Region—such as pasture improvement—can produce a greater rate of return on a short-term basis. There are attractive opportunities for capital owners to invest in other activities than forest production. In fact, there is a temptation for the forest owner to liquidate his timber growing stock and invest the money thus realized in some other enterprise. However, the risk involved in alternative long-term investments is probably greater than in forest production, so the real rate of interest may not be higher. Once most forest land in the Region is under management, there will be much less danger of loss from fire and insects. An active forestry business will also lower losses through prompt salvage of damaged trees.

Nevertheless, we might explore the effect of a higher interest rate on the efficiency of forest land use. If we use four percent instead of three in the calculations, discounted economic rent is lower on all classes of land but the relative efficiency of the classes is unchanged. Under intensive management, the increased interest rate makes Class 50 land submarginal for forest production under either Level I or II management. The economic rent under Level I is changed from $25.75 to a negative value of −$3.31. Despite the higher interest rate, all other classes of land remain supermarginal at Levels I and II.

Unless new investment opportunities appear which can absorb large quantities of capital, forest production should remain sufficiently attractive to permit efficient use of forest land in the Region. This conclusion is strengthened by the fact that most of the capital concerned is not borrowed "dollar" capital, but rather is in the form of growing stock. This capital can be obtained for alternative investment only by liquidating the growing stock. Since the small landowner will do most of his own work, he will require little "dollar" capital to maintain his growing stock. He is not likely to liquidate a profitable forestry enterprise unless he sees a good chance of making much larger returns from an alternative use of the funds thus freed. In most cases the total amount of capital a small owner could obtain by liquidating his forest growing stock would not be enough to embark on some other high-yield enterprise anyway.

Changes in agriculture. Forest production in the Region is closely tied up with agriculture because so much forest land is on farms. Any major changes in agriculture are likely to affect forest production one way or the other. The changes we can foresee now fall into two classes: changes in the size of operating farm units, and changes in the kind of agricultural products produced.

The present trend in the Southeast is toward larger operating farm units which permit more mechanization and also more efficient management. Since forest lands can be operated more efficiently in large units, this trend should favor more efficient forest management in the Region.

There also has been a trend toward more livestock on farms and a shift away from row crops. Livestock farming is less compatible with forest production than cotton or general farming because of conflicting labor requirements, and a major shift to livestock could mean a shortage of labor

for forestry work. Permanent pastures also will compete with forests for the use of the same land, while row crops would not because little existing forest land is suitable for row crop production. Analysis of 207 farm plans prepared in the Clarke County Work Unit of the Oconee River Soil Conservation District disclosed that they recommended clearing eight percent of the forest land on these farms, mostly for permanent pasture. We can assume that any further expansion of livestock farming in the Region will reduce the area in forest production. Since the most productive forest land usually is cleared, this may alter somewhat the efficient pattern of forest land use.

Increase in industrial ownership. The recent rapid expansion of the pulp and paper industry has been accompanied by extensive land purchases. Pulp company holdings are small in the study Region at present, but as competition for wood becomes severe, new or existing mills may acquire land. At the same time, the larger lumber companies may feel compelled to expand their landownership in self defense. It is quite probable that the future will see a considerable increase in industrial ownership of forest land in the Region.

Two opposite effects could result from increased industrial ownership: very efficient management of the industrial lands and a strenthening of the bargaining position of the wood users, with reduced markets and lower prices for other landowners. Increased industrial ownership may lead to more efficient forest land use in the Region, but the effect might be a dual one of increased efficiency on industrial lands and decreased efficiency on non–industrial lands.

Decentralization of industrial and residential areas. Because of the improvement of the Georgia highway system and the increased use of truck and automobile transportation, industrial and residential areas no longer concentrate in cities and towns and along railroads. Many new industries are locating in small towns or even in rural areas, and the residential areas of the larger cities and towns are spreading far out into the country. In the study Region this is quite noticeable in Gwinnett and Rockdale Counties, the western portions of which are rapidly assuming the appearance of suburbs of Atlanta.

Forest land is especially attractive for industrial and residential development because of its relatively low price and natural aesthetic value for home sites. A continued decentralization of industrial and residential areas seems certain to reduce the forest land area in the Region. Whether this will be enough to change the pattern of forest land use which is most efficient for the Region will depend on how industrialized the Region becomes.

Efficient Forest Production on a Regional Basis

Our analysis of efficient forest land use for the study Region has become progressively more realistic. We will now take the final step of recognizing that the Region, must find markets for its products. We have seen that forest production not only is profitable on most lands in the Region, but is most profitable at high management intensity, which also means high output. It is sufficiently profitable to pay the prices necessary to obtain the services of labor and capital. But can the possible output of such intensive management be sold?

A timber growth goal for the region. The Forest Service, in its Timber Resource Review, has estimated that in the year 2000 the United States will require 55 billion board feet of lumber and 18 billion cubic feet of all wood (Rettie, 1955). In 1946 the Forest Service attempted to apportion growth goals among various sections of the country in accordance with the productive capacity of forest land resources (Forest Service, 1946). It was their opinion that the states in the Southeast could provide 24 percent of the nation's wood production on a long–time basis. If we divide this

quota purely on the basis of land area, the study Region should provide slightly under 0.2 percent of the total wood requirements of the country. Assuming that all other sections of the country contribute their fair share to national production, this is probably a reasonable estimate of the amount of wood which the study Region can expect to sell. If we accept both Forest Service estimates, a long-run growth goal for the Region is: 110,000,000 board feet of lumber and 35,000,000 cubic feet of all wood products.

The general problem of meeting the growth goal.

Current regional cut. There are no exact figures on the current annual timber cut from the forest lands of the Region, but we can build up a reasonable estimate. The 1954 pulpwood cut in the ten counties was 72,000 cords (Stover and Christopher, 1955). The most recent figure for lumber cut by counties is for 1946 (Census, 1948). In that year a total of 76,000,000 board feet of sawlogs was cut in the Region, and the current cut probably approximates that figure. The Forest Survey in South Carolina found the average home consumption for fuel, posts, and miscellaneous uses cut from sound live timber to be about 11 cords per farm (McCormack, 1948). Applying this figure to the study Region, we get a total of 120,000 cords for farm use. Finally we may estimate that the cut of veneer logs, poles, piling, and miscellaneous other products amounts to three million cubic feet per year. When all these figures are brought together we find that total current production approximates 76,000,000 board feet of lumber and 30,000,000 cubic feet of all wood products.

The recent cut in the Region has been below the estimated growth goal but has exceeded the 22 million cubic feet which would have been the Region's share of the 1952 national consumption of 11.2 billion feet (Rettie, 1955). Thus the problem for the Region is to maintain its present output and gradually expand it as time passes.

Potential regional production. The potential production with all of the forest land in the Region under management at the same level is as follows:

Level	I	58,000,000 cubic feet
Level	II	42,000,000 " "
Level	III	14,000,000 " "
Level	IV	11,000,000 " "

These are long-run production figures. The Region today is harvesting 30 million cubic feet of wood a year and could continue to do so for some years. But this means cutting into the naturally-produced forest growing stock of the old-field pine stands. If Level III or IV management were applied to all of the Region's forests their condition would continue to deteriorate and the possible annual yield would eventually sink to the total figures given above. At these management levels production would be much below the growth goal, demand would not be satisfied, and the efficiency (and profitableness) of forest land use could be increased by intensifying management. If all of the Region's forest lands were managed under Level I or II, total production would eventually be greater than the growth goals. At these management levels supply would exceed demand, prices would decrease, and the total yield might not find buyers even at low prices.[5]

The answer to the problem of adjusting total output to the growth goal is to manage part of the land at high intensity levels and the rest at low intensity. Whether this answer leads to efficient forest land use will depend on which classes of land we manage at the various levels.

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[5]This assumes that the forest lands in the rest of the country would be managed at an equivalent level of intensity. Planning cannot safely assume that methods which prove highly profitable in one region will not be applied generally, with the possible consequence of profits being reduced or eliminated everywhere.

Meeting the growth goal efficiently. Our analysis thus far shows that land is not the scarce factor in forest production in the Region. There is enough land to produce more than the growth goal—more than the market can reasonably be expected to absorb. The problem of efficiency is to produce enough to attain the goal with the least amount of capital. Our aim must be to maximize the rate of return on the capital investment. We have seen that the revenue–cost ratio can be maximized on any given class of land by raising the intensity of management to Level I. The most efficient way to attain the growth goal, therefore, is to select those classes of productivity, present condition, and ownership which produce the highest revenue-cost ratios and intensify their use to Level I. All other lands should be managed at the minimum or Level IV.

The most efficient ownership classes are the Non–farm and Very Large farms. If all the forest land on these classes were managed at Level I and all other land at Level IV, the total regional production would be only 31.6 million cubic feet. This is about 3 million short of the growth goal. It seems doubtful anyway that all very large owners will manage their forest lands at Level I intensity. The solution must lie in some combination of portions of the various classes under Level I management with all other lands under Level IV.

The models presented in Table 19 show three possible ways of meeting the growth goal efficiently. In these models intensive management is applied to only 80 percent of the ownership because it seems reasonable to assume that this proportion of the owners might intensify their management. Intensive management is not applied to any of the Small farms in these models. The number of Medium farms involved is progressively reduced in Models 2 and 3 by extending management to additional land classes on the larger ownerships.

The results of applying these models to the Region are presented in Table 20.

TABLE 19. Model land use patterns to meet the growth goal.

Management Level	Ownership Classes	Land Classes
	MODEL 1	
	80% of Non-farm	80 A and B
I	Very Large farms	70 A and B
	Large farms	60 A and B
	Medium farms	
IV	All others	
	MODEL 2	
	80% of Non-farm	80 A, B, C, D
I	Very Large farms	70 A and B
	Large farms	60 A and B
		50 A and B
	80% of Medium farms	80 A and B
		70 A and B
IV	All others	
	MODEL 3	
	80% of Non-farm	80 A, B, C, D
I	Very Large farms	70 A, B, C, D
	Large farms	60 A and B
		50 A and B
	80% of Medium farms	80 A and B
IV	All others	70 A

TABLE 20. Regional results of production models.

Model	Total Production (cubic feet)	Revenue-cost Ratio[1]	Owners under Level I Management
1	35,100,000	2.41	2,567
2	35,000,000	2.42	2,222
3	35,100,000	2.41	1,942

[1]The cost includes education and advice for the private owner.

There is little choice among these possible solutions except for the number of owners who would practice Level I management. The cost of the education and advice which these owners need to practice this intensity of management is absorbed equally well in the three solutions, as is indicated by the revenue–cost ratios. However, there are reasons why the solution requiring the smallest program of education and advice

might be preferred; we will consider these later. Other models can be worked out which attain the desired total annual production by using different management levels on different land classes. So far as I can determine by trial, the three presented above are the most efficient land use patterns which will produce a regional output of 35 million cubic feet.

Uncertainty requires flexibility in planning. Any estimate of future events—no matter how carefully prepared—will likely prove to be wrong. Crafts (1955) says that "estimates of future requirements made in the past have tended to be short of actual demand at the target date." Most of the estimates he quotes were made during the depression; our future outlook is usually colored by our circumstances at the time. In 1952, six years after the appearance of the Reappraisal Reports (Forest Service, 1946), consumption of both lumber and all industrial wood had failed to reach these more optimistic estimates of average 1950–55 requirements. Considering that growing stock started today will not be harvested for 45 to 70 years, this item of uncertanty is of major importance in forestry planning.

If the growth goal used in our analysis should prove to be an overestimate, the result will not be too serious. There will be over–production of wood with a probable drop in prices, and long-run earnings will be less than anticipated. But prices will have to fall drastically before the lands recommended for Level I management in the proposed solutions become submarginal. If it becomes apparent with passing time that demand is not holding up to anticipations, the intensity of management can easily be lowered by omitting cultural operations or carrying them out less intensively.

If on the other hand the growth goal should prove to be an underestimate, the situation will be serious. Under the proposed solutions, a large area of the more easily managed present condition classes will be allowed to deteriorate to the condition maintained under Level IV management. In their present condition, these stands can quite cheaply be put under a high level of management. Once they reach a condition characteristic of Level IV management, it will be much more expensive to intensify their management. More serous than the cost, however, is the time required to raise land from Level IV to Level I or II management. Since this can be done only by clearing the hardwood stand characteristic of Level IV and planting the area with pines, the increased yield will not be obtained for 45 to 70 years after the decision to intensify management is made.

A flexible plan to meet the regional growth goal. The trouble with the models presented is that they are too rigid. Because only the highest and lowest levels of management are in use, production cannot easily and economically be adjusted either up or down except over a long period of time. The risk in such a policy is evident. Efficiency in production requires a rigid pattern of management, but in the long run this rigidity itself may cause land use to be inefficient. Some of the lands must be managed at an intermediate level from which their output can readily be adjusted upward or downward, even though this may be a less efficient use under present conditions. We must purchase flexibility in land use at an apparent sacrifice in efficiency.

In our first three models, we reached the growth goal by placing under Level I management 17 to 23 percent of the ownerships and 49 to 50 percent of the forest land. The remaining ownerships and land operate at Level IV. We can make these programs more flexible by managing part of the land at Level II, from which production can more readily be increased or decreased. To do this we must place a larger percentage of the ownerships and land under the higher levels of management.

Two possible ways of meeting the

TABLE 21. Model land use patterns to meet the growth goal flexibly.

Management Level	Ownership Classes	Land Classes
	MODEL 1	
	80% of Non-farm	80 A, B, C, D
	Very Large farms	70 A, B, C, D
	Large farms	60 A, B, C, D
II	Medium farms	50 A and B
	80% of Small farms	80 A and B
		70 A and B
		60 A and B
IV	All others	
	MODEL 2	
	80% of Non-farm	80 A and B
I	Very Large farms	70 A and B
	Large farms	60 A and B
	80% of Non-farm	80 C and D
II	Very Large farms	70 C and D
	Large farms	50 A and B
	80% of Medium farms	80 A and B
		70 A and B
		60 A and B
IV	All others	

growth goal flexibly are shown by models in Table 21. In the first model Level I is not used at all, while in the second model a combination of Levels I and II is used. The results of applying these models to the Region are shown in Table 22. The second model is obviously a more efficient scheme than the first for meeting the growth goal flexibly. The efficiency of the use of capital is higher. In addition, only 25 percent of the ownerships and 57 percent of the land must be managed at a higher intensity than level IV, as compared to 60 and 74 percent in the first model; this means a smaller program of education and advice.

By raising the intensity of management to Level I on those lands classified for Level II management in Model 2, the total production can be raised to 38,400,000 cubic feet. Because this pattern of land use is flexible, production can be expanded by 8 percent fairly quickly and easily if demand requires it. We have achieved this flexibility through a less efficient use of capital, as indicated by the revenue-cost ratio of 2.04 compared to the

TABLE 22. Regional results of flexible production models.

Model	Total Production (cubic feet)	Revenue-cost Ratio[1]	Owners under Level I Management
1	35,300,000	1.81	6,720
2	35,600,000	2.04	2,814

[1]The cost includes education and advice for the private owner.

2.41 obtained in the earlier rigid models. From the Regional viewpoint, however, this less efficient use of capital is justified by the reduced risk of future underproduction and wood shortages.

The pattern of land use which appears to meet the Regional growth goals most efficiently, with allowance for flexibility, is presented in Table 23.

The regional forest management policy required. The intensity pattern of land use shown in Table 23 provides a goal for efficient use of the forest lands of the

TABLE 23. An efficient flexible pattern of forest land use intensity for the Region.

Condition Class	Productivity Class 80	70	60	50
	Level I Management			
A and B	80% of Non-farm, Very Large and Large farms			None
	Level II Management			
A and B	80% of Medium farms			80% of Non-farm, Very Large and Large farms
C and D	80% of Non-farm, Very Large and Large farms			None
	Level IV Management			
A and B	Small farms and 20% of all others			Small & Medium farms and 20% of all others
C and D	Small and Medium farms and 20% of all others			All ownerships

Region. A Regional policy to achieve this efficient use should consist of the following:

1. All forest lands in the Region should be managed at a minimum intensity of Level IV; i.e., adequate fire protection should be provided for all lands.

2. Small farm ownerships should be managed at Level IV. No effort should be made to encourage these owners to intensify their management.

3. Medium farm holdings of Condition Classes A and B on Class 80, 70, and 60 land should be managed at Level II. An attempt should be made to get 80 percent of these holdings under management at this level. No effort should be devoted to the other Medium farms.

4. Condition Classes C and D should be managed at Level IV, except on the Non–farm and Very Large and Large farm holdings of Class 80 and 70 land. An attempt should be made to get 80 percent of these under management at Level II. No effort should be devoted to other C and D Class stands.

5. The Class A and B stands on the Non–farm and Very Large and Large farm holdings should be managed at Level I on Class 80, 70, and 60 land; and at Level II on Class 50 land. An effort should be made to get 80 percent of these under management at these levels.

In summary, any Regional program of forest management should concentrate on the larger ownership classes, the most productive land classes, and the best present condition classes. If intensive management is achieved on these lands the resulting Regional output will be all that apparently can be marketed profitably. A minimum intensity of management will suffice on the least productive lands and most difficult ownerships. They should be permitted to operate at this minimum level.

The Transition to More Efficient Forest Land Use

We have now arrived at a plan of efficient use for the forest lands of the Region. But the present use of these lands does not correspond at all to this efficient plan. If efficiency is to be achieved, management must be intensified on almost all forest lands in the Region. This intensification will have to be done gradually during a period of transition. There is no central Regional authority which can prescribe changes in land use and force landowners to adopt them and, presumably, under our economic and political philosophy there never will be. The transition must come through education and encouragement of the private landowners by various agencies interested in the forest land resources of the Region. Let us now analyze the problems which must be solved during this transition period.

Regulating the cut on a regional basis. Any long–range policy for the Region must aim at a sustained yield of products from the forest lands. Because of short–time fluctuations in economic conditions, annual harvests will vary from year to year and the sustained yield figure should approximate a normal around which the actual harvests vary. The area to be cut over each year can be determined from the rotation on which the forest is grown, which varies with the level of management and the productivity class. In Table 24 the total area of forest land in the Region is divided by classes and by the levels of management required for efficient use.

We can find the area to be cut over annually by dividing the total areas in Table 24 by the rotations required for effi-

TABLE 24. Area distribution for efficient forest land use in the region.[1]

Condition Class	Productivity Class 80	70	60	50	Totals
		Level I			
A and B	50,480	136,400	102,480		289,360
		Level II			
A and B	13,680	37,200	28,000	23,680	102,560
C and D	8,480	24,720			33,200
Totals	22,160	61,920	28,000	23,680	135,760
		Level IV			
A and B	29,840	80,400	60,520	20,320	191,080
C and D	7,520	21,280	69,000	36,000	133,800
Totals	37,360	101,680	129,520	56,320	324,880

[1]Areas in acres.

cient use of each class and level of management. These annual cutting areas are shown in Table 25. If the forest lands are cut over at the rate shown, and management is applied to them, the entire Region will be on a sustained yield basis under efficient management at the end of the longest rotation, which is 70 years on Class 50 land under Levels II and IV. This gives us a general plan of approach to the regulation of the forest lands of the Region.

The schedule in Table 25 calls for harvesting 6,948 acres of Class A and B land per year under practices which will permit these lands to be managed thereafter at Level I or II, as the case may be. 566 acres of Class C and D land are to be cleared per year and planted with pine so they can be managed at Level II. In addition, 5,745 acres are to be cut over on land to be managed at Level IV. On the average, a total of 13,259 acres of forest land will be harvested in the Region each year.

If such a schedule is followed, the Region will be producing an annual amount of timber equal to the growth goal by the end of the first rotation. But can the present rate of timber cutting be maintained in the meantime? In order to produce the same amount as is now being cut, the average volume removed from the 13,259 acres cut over each year will have to be 2,260 cubic feet of wood, including 5,730 board feet of sawtimber. The logical approach is to cut the oldest stands first, which will be those with the greatest present volumes. The thinnings to be made in many present stands may fill most of the current demand for pulpwood and firewood. Stands which are not cut immediately will continue to increase in volume and with fire protection and management should contain greater volumes when ready for harvest than do the present merchantable stands.

It appears safe to concentrate immediate cutting on the lands marked for Level IV

TABLE 25. Areas to be harvested annually to place the region's forest lands on sustained yield.

Condition Class	Productivity Class 80	70	60	50	Totals
		Level I			
A and B	1,122	2,480	1,708		5,310
		Level II			
A and B	249	620	431	338	1,638
C and D	154	412			566
Totals	403	1,032	431	338	2,204
		Level IV			
A and B	597	1,608	1,008	290	3,503
C and D	150	426	1,151	515	2,242
Totals	747	2,034	2,159	805	5,745
Total					13,259

management in the Class A and B stands, which are those with the greatest present volume. This should make it possible to maintain, and perhaps even increase, the present cut during the transition period. If this is to be successful, however, the present practice of cutting young, fast-growing stands must stop and these stands must be carried as long as possible.

Present status of forestry programs in the region. At present there is only a limited program of forestry in the Region. Eight of the counties are under adequate fire protection; the other two have no organized protection, though some assistance is received from Georgia Forestry Commission personnel in adjoining areas when emergency situations occur. Assistant District Foresters in Gainesville, Newnan, and Washington offer management assistance but each of these men covers a district containing over three million acres of forest land. Conservation foresters of the pulp and paper companies buying in the Region also give some assistance in marking and tree planting. Two Extension Foresters cover the entire State and are limited to rather general educational work. The Soil Conservation Districts include forestry in their farm plans but do not employ a technical forester in their program in the Region. The services of consultants are available to landowners who will pay for them,

but the number of consultants is not adequate to handle a Regional program of intensive management.

Technical assistance required for efficient land use. Approximately 425 thousand acres of forest land in the Region should be managed at Levels I and II. These intensities of management require technical work which the landowners cannot do for themselves. If the lands are to be managed efficiently, a number of technically competent men must be employed in the Region. An average of 36,600 acres of young pine stands will be thinned each year and this operation alone will keep ten technically trained tree markers busy on a year-round basis. Another man will be needed to mark the areas to be harvested each year. Almost four men will be required for supervision of other forestry operations (general overhead). All of these men must be competent silviculturists, but they need not be men of long and wide experience. Fire protection will require the service of almost seven men who might not be foresters but must have considerable technical knowledge and experience. Cruising and selling will involve half a man year, which may be provided largely by consultants. Education and advice will require almost six men who must be graduate foresters with considerable ability in educational and promotional work. All told the equivalent of twenty–eight men will be needed to handle the technical forestry work in the Region as follows:

Marking for thinning	10.0 man years
Marking for harvest	1.0
General overhead	3.9
Cruising and Selling	0.5
Fire protection	6.8
Education and advice	5.6
Total	27.8 man years.

The problem of marketing. We noticed earlier that an owner must have a minimum amount of timber before he can interest a buyer. This will prevent annual sales on small properties even under efficient management. But it is even more serious right now, since the volume per acre in stands ready for harvest is much less than it will be under intensive management. In most parts of the Region it is probably impossible to make a saw–timber sale today involving less than 15 acres. This means that the smallest part of the various ownership classes which can be harvested at one time is as follows:

Non–farm and Very Large farms	1/25 of area
Large farms	1/9 of area
Medium farms	1/4 of area.

It is possible to harvest the timber from all land on a property at one time and wait a full rotation for the next harvest. But several conditions make this generally impracticable. A property may contain stands of various ages, only the oldest of which should be harvested now. Or one property may contain lands of different productivity which should be managed on different rotations. If the whole property is harvested now, the different classes of land will not be ready for the second harvest at the same time. This may be a minor objection if the difference in rotation is not large. A third objection is more serious. The prospect of waiting anywhere from 45 to 70 years for another crop may eliminate any incentive for the owner to manage his forest lands. It will be best to manage the individual properties in such a way that crops are harvested at the shortest possible intervals.

If the proportion of the area given above must be cut at one time in order to make a sale, the shortest interval between cuts will be:

2 to 3 years on Non–farm and Very Large farms
5 to 7 years on Large farms
14 to 16 years on Medium farms.

The most serious effect will be on the incentive of the Medium owners. But even Large farm owners may be discouraged by the prospect of an average six year wait

between incomes. The present market structure is thus a very real obstacle to the attainment of efficient forest land use in the Region. Unless some means is found to provide markets for small quantities of timber, completely efficient use of the forest lands may be impossible.

Starting the management program. The conversion of the present inefficient use of forest lands in the Region to an efficient pattern is a major undertaking. Fortunately, the nature of the problem itself is such that is must be accomplished over a long period of time so we can start on a small scale and build up gradually.

The key to efficient forest land use is the group of foresters and technicians who must promote the needed changes, educate and advise the landowners, and furnish the required technical assistance. It would be impossible under present conditions, and inadvisable anyway, to put the ultimately-needed force of 28 technicians to work in the Region immediately. Existing programs provide a core of technical advice and assistance equivalent to about six men. The problem is to expand this core gradually but also efficiently.

Adequate fire protection is essential to forest management and should be extended to all forest lands in the Region at the first possible moment. This can be accomplished more easily than other phases of the program because technical supervision is already available in the Forestry Commission districts which cover the Region. Foresters are not absolutely necessary, though desirable, for the local administrative positions, and personnel problems should not hinder expansion of the fire protection program.

The critical job will be promoting interest in intensive management among the owners of forest lands. This must be accompanied by the technical assistance these owners need to carry out the cultural practices. The best entering wedge with a landowner is to help him harvest efficiently the timber from part of his land. If the owner of 400 acres harvests 15 with the guidance and assistance of a forester and is convinced he has done well thereby, it should be relatively easy to get him to extend management to the rest of his land. The result of assistance with 15 acres may be 400 acres under management, if the owner continues to receive education and advice. By contrast, if the owner of 60 acres is helped to harvest 15, the best result can be only 60 acres under management, although the cost is practically the same. It is most efficient to direct the original education and assistance program toward the largest owners.

A practical promotion program will have to work with any owner who is interested, regardless of how much land he owns. But a brief example will show the advantage of concentrating on the largest owners first. Let us assume that it is possible to start with the largest owners and gradually work down to the smallest. If 1/25 of the forest area on the Non-farm and Very Large farm holdings is harvested in the first cut, the total area cut over on the properties managed at Levels I and II will be 8,195 acres. The recommended annual cutting area for the Level I and II properties (other than Class C and D stands) is 6,948 acres. Thus the entire cut in the first year can be concentrated on the Non-farm and Very Large farm Class. With 15 acres cut on each property, 463 properties are partly cut over in the first year. The total forest area on these properties, or 172,000 acres, will start to receive management in the first year if the owners are sold on the program.

In the second year, 1,247 more acres can be cut on the Non-farm and Very Large farm Class, and the remaining 5,701 acres are cut on the Large farm Class. Since the total forest area on these properties is 82,000 acres, a total area of 254,000 acres is placed under management in the first two years. Since this amounts to 60 percent of the land to be placed under Level I and II management, the program

has achieved over half its goal in the first two years. In the third year most of the harvest consists of the second cut on the Non–farm and Very Large farms, and the area under management remains about the same. In the fourth year the harvest is extended again to new properties. Each year thereafter the increment to the managed area will be smaller, but by the end of the first rotation all the required land will be under management.

The efficiency of this approach can also be seen in the need for technical help. In the first year, 463 properties are placed under management, which requires the services of one Education and Advice Forester. An additional forester is needed to mark the stands for harvesting, and if the education is sufficiently successful, one or two more to mark for thinnings and supervise other cultural work. Between two and four foresters are needed for the first year, other than for fire protection. In the second year another Education and Advice Forester is needed, and thinning and cultural work will require the services of two or three, making a total of five or six foresters. In the third year the harvest returns to the lands of the first class of owners, so little additional personnel is needed. In the fourth year a new group of owners must come into the picture, and total needs rise to seven or eight foresters. The build–up during the first years of the program might appear somewhat as follows:

Year	Foresters	Owners	Acres
1	3	463	172,000
2	5	926	254,000
3	6	950	257,000
4	8	1,390	316,000
5	9	1,400	318,000

The need for immediate action. Our analysis shows that immediate steps should be taken to intensify the use of forest land in the Region. Land use practices now followed are converting stands from the desirable Class A to Class B and, even more serious, to Classes C and D. Management of the Region's forest lands could fairly easily be intensified today without a reduction in current harvests. The longer this intensification of use is postponed, the more difficult and costly it will be. If much more of the forest is permitted to revert to Class C and D, there inevitably will come a time when harvests of the present size cannot be continued. The full results of intensive practices applied today will not accrue for 45 to 70 years, and the longer the start is postponed, the farther away in the future will be the benefits.

Present forestry programs are quite inadequate to bring about the intensification of land use which the interests of the Region require. Education, advice, and technical assistance are needed on a scale far surpassing anything now in effect. Because it will take time for the landowners to accept and use this technical help, it should be made available to them immediately and in increasing amounts as they learn to use it.

Social Implications of Changes in Forest Land Use

Our analysis thus far has dealt with economic variables and we have measured the success of land use adjustment by the economic results obtained. But all effects of changes in land use cannot be expressed as economic values, and we must now consider some of the other effects. Their measurement in terms of human gain or loss is uncertain and is not simplified by any attempt to balance them against economic effects. The decision as to Regional action when both economic and non–economic results are considered must remain the difficult problem of our policy making bodies. All we can do here is point out the effects and their possible implications.

The small farmer not directly benefited. One of the serious social problems of the South is the small low income farmer. Our analysis shows that efficient use of the forest land resources of the Region would not directly benefit these small farmers.

Timber can be grown more efficiently on the larger ownerships, and the Regional growth goal is not large enough to require intensive management of the Small farm woodlands. Besides, there just is not enough forest land on a Small farm to add materially to the farm income even if it is managed intensively. Table 16 shows that a Small farmer who has all Class 80 land and manages it intensively at Level I, can average only $250 annual income from his forest. He could supplement his income this much by working forty days a year off the farm. When we recall that because of the market structure his income from forest land cannot come annually, but only in large lumps at long intervals, it is plain that he would do better to try to find supplementary employment off the farm. This is even more true for farmers in general, because the $250 income is a maximum which can be obtained only under the most favorable conditions, and the present forest condition and class of land on most Small farms will yield only the lower incomes shown in Table 16.

Efficient use of the Region's forest lands will require about one hundred man years of labor in timber growing. Much of this will have to be hired labor on the larger ownerships and should provide off the-farm employment for many small farmers. It cannot fill all the supplementary labor needs of the almost six thousand Small farmers in the Region, but it will indirectly stimulate other forms of employment, as we will see later. The efficient forest land use pattern proposed for the Region should contribute somewhat to the solution of the problem of the small low-income farmer.

Trend toward larger farms encouraged. The trend toward larger farms in the Region is a result of increased income from more efficient use of land, labor, and capital on larger operating units. Both the landowners and their employees share in this increased income. The concentration of timber production on the larger ownerships for efficient forest land use will contribute to this trend. It will be to the advantage of the larger owners to expand their forest land holdings because this will simplify their management and marketing problems. Small farms, particularly those with limited areas of cultivable land, will become relatively less efficient and more likely to be disposed of.

There is another side to this picture. As the trend continues, the number of independent farm operators will decrease and the proportion of the population in the employee class, those dependent on wages, will increase. This is the nationwide trend, but we may question how far it is desirable for it to go. The effect of the proposed change in land use in the Region will be a concentration of economic power in fewer and fewer hands and a reduction in the number of self-sufficient people in the community. It might be argued that it is desirable to keep the control of productive resources more widely distributed and that this would justify less efficient economic use of the forest lands in the Region.

Stability and expansion of industry in the region. The lumber industry is the major wood user in the Region. It consists largely of small portable mills which move at short intervals because of the present condition of the forests. The output of these mills is mostly lower grades of lumber because the small old-field pine trees they saw will produce little high grade lumber. The mills must operate close to their raw material supply because they cannot afford to transport very far these low value logs with their large proportion of waste. Consequently, most of these mills are not efficient. There are a few larger permanent mills which produce a higher grade of lumber and haul in logs from as far as fifty miles. Sustained yield (on an area basis) production of higher quality trees under intensive management would permit an increase in the number of efficient, permanently-located mills because they would have a sure and continuous supply of logs within a short radius. The change to more

efficient forest land use should eventually produce a more efficient and profitable lumber industry in the Region. In fact, the lumber industry could in time expand its production considerably. The effect on the Region as a whole would be desirable. Employment in the lumber industry should increase, and with more efficient operation, wages should be higher. Some of the present marketing difficulties may solve themselves in this process, because a permanent sawmill obtaining all its logs within a short radius can afford to log tracts too small for a portable mill setup. This will be especially true when the higher quality trees produced under management are ready for market.

The manufacturing plants of the pulp and paper industry are located outside the Region, but these companies have wood procurement organizations within the Region. Their procurement problems would be simplified by the sustained production of wood from thinnings, which would permit them to buy from the same owner at intervals. Most other wood products are shipped out of the Region for processing. It is possible that sustained production will permit the development of concentration yards through which small quantities of these minor products could be disposed of at good prices.

In this area industry has always obtained most of its wood from the lands of private owners. The gradual depletion of these forests has impelled many industries to acquire lands of their own and manage them for timber production. These industry-owned lands are some of the most efficently managed in the South today. The post-war expansion of the pulp and paper industry has stimulated this industrial land acquisition, which appears to be largely a defensive action to insure a raw material supply. Management of the forest lands of the Region at an efficient intensity would guarantee raw material for industry. This might halt the expansion of industrial ownership and possibly even reverse the present trend. Thus the change in land use might have an effect opposite to that suggested in the preceding section. It could lead to the maintenance of numerous forest production units managed by individual owners rather than the concentration of ownership in the hands of a few large industrial corporations.

Low-productivity lands not uniformly distributed. The productivity of land in the Region increases generally from northeast to southwest. Practically no Class 80 and very little Class 70 land is found in Franklin County at the northeast extremity. As we proceed westward, the average productivity improves, and Class 50 land gradually disappears. Newton and Rockdale Counties in the southwest extremity show a high proportion of Class 80 land.

The areas where the low-productivity lands are concentrated, and Franklin County in particular, pose a problem for the Region. Our proposed efficient land use pattern will not have Class 50 lands managed at Level I anywhere; it will have lands of that Class managed at Level II only on larger ownerships. This means that as a whole the forest lands of Franklin County will be managed much less intensively than those in other counties. Since the potential productivity of Class 50 lands is low anyway, the forests of Franklin County will not contribute much to the income of their owners. If agriculture is not profitable and other sources of employment are not available, the population of such an area of poor-quality forest land cannot depend on the forests for a livelihood. The only solution in such a case is for the people to emigrate in large numbers. The forest lands might then be blocked up into industrial or public ownerships and managed more efficiently. As with the small farmer generally, the solution to the problem of the landowner with low-productivity forest land will not be found in more intensive management of that poor land. If he is to be helped, it must be done in some more effective way.

Optimum Intensity of Forest Land Use for the Study Region

Our purpose in this study has been to carry through an experimental determination of the optimum intensity of forest land use for a sample Region. We have explored various aspects of the problem and gradually revised our original version of optimum intensity in the light of our findings. Now we can draw all the threads together with reference to our original objective of maximizing economic welfare and see the complete pattern of optimum intensity for the study Region.

Under present product price and cost conditions, timber can be grown at a profit on most forest lands in the Region while all productive factors are paid at their alternative rate of compensation. If the profit were distributed among the productive factors, they would actually earn more in growing timber than they could in the best alternative employment. Economic welfare will thus be higher if these factors are used to grow timber than if they are used for some other production.

On all forest lands in the Region it is more profitable to grow sawtimber than pulpwood or other bulk products. If we assume that stumpage prices of wood products reflect their marginal value to their consumers, general economic welfare will be higher if production is concentrated on sawtimber than if it were concentrated on other products.

Forest land can be managed at various levels of intensity. Output and costs vary with the intensity. Within the range of intensities studied, higher levels of management intensity show greater profits than do lower levels. A given amount of productive factors will produce the greatest output if used in intensive land management. General economic welfare will thus be greater if the forest lands in the Region are managed at high levels of intensity than if they are managed at low levels.

Forest land in the Region varies in productivity. The same amount of the productive factors will produce a greater output on high-productivity land than on low. Where there is a limit on the amount of other factors available or on the output, economic welfare will be greater if production is concentrated on the most productive lands.

The present condition of forest stands varies in the Region. The cost of organizing a forest for permanent yield is less if management starts with some classes of stands than if it starts with others. The same amount of productive factors applied to present pure pine stands will produce a greater long-time output than if applied to present hardwood stands. Economic welfare will be greater, therefore, if we concentrate production of a limited output or the use of a limited amount of other factors on the most profitable present condition classes of stands.

Various classes of owners control the forest land in the Region. The problems of forest land management and the public cost of encouraging private owners to manage their lands vary with the size of ownership. A given output of wood can be produced at less total cost on large properties than on small. General economic welfare will thus be greater if production is concentrated on the most efficient classes of ownership instead of being distributed equally over all ownerships.

Changes in external conditions which affect the prices received for products grown in the Region or the prices which must be paid for the services of productive factors will cause the profitability of forest land use to vary. They may indicate that general economic welfare will be greater if the factors are used for some other purpose than forest production, but they will not change the above pattern of relationships. If economic welfare can be increased by producing timber, it will be increased most by producing it in the manner described.

Wood is a raw material, and in most of its uses is combined with many other goods and services before emerging as a con-

sumer's good. The amount of wood consumed is determined more by the other conditions involved in its use than by the price of the wood itself. This means that there is some limit to the amount of wood which can be sold from the Region, and this limit cannot be expanded very much by reducing the price. The amount of wood which can be sold from the Region is less than the amount which can be produced under intensive management of all forest lands, assuming that the same intensive management is applied to lands outside the Region. Economic welfare will be highest if this amount of wood is produced at the lowest possible cost. Production should be concentrated, therefore, on the lands where it will be most efficient.

Timber production, however, is a long–time enterprise. The silviculture we practice today is planned in anticipation of prices many years hence in markets which we think will exist then. We cannot be certain what those prices actually will be, or whether those markets will even exist, when our crop matures. The only possible insurance against this uncertainty is to have our management flexible enough so that we can make adjustments as errors in our anticipations become apparent. Production can be increased fairly easily and quickly from the higher intensities of management; under the lower intensities, the natural reversion to hardwoods makes expansion of production costly and time consuming. Long–run general economic welfare will be greater if part of the lands are managed at an intensity somewhat lower than would be most profitable in the short run, but high enough to maintain them in pine.

Intensity of land use has two aspects on a regional basis: the amount of the land in the region which is used and the amount of the other productive factors which are combined with this land. We can summarize the economic optimum intensity of forest land use for the Study Region as follows:

1. The most profitable classes of land, present stands, and ownership managed at a high level of intensity to make regional land use as efficient as possible.
2. The next most profitable classes managed at a somewhat lower level of intensity to provide flexibility in case the future demand is larger than anticipated.
3. All other classes managed at the lowest level of intensity because adequate fire protection for all lands is necessary if the best lands are to be protected. Otherwise, these classes could be left unmanaged.

This regional intensity of forest land use will yield the greatest economic welfare which can be attained with adequate allowance for uncertainty.

This optimum intensity is much higher than the current level of management in the Region. General economic welfare can be increased by changes from the present intensity of forest land management toward the optimum intensity. Such changes must be promoted and developed through education of, and technical advice and assistance to, the private landowners. The programs now trying to improve forest land use in the Region are not adequate to attain the optimum intensity. An expanded forestry program in the Region would, therefore, increase economic welfare.

A regional program aimed at optimum intensity of forest land use faces numerous problems which must be solved before the optimum can be attained. The major problems are stimulating the private landowners to intensify the management of their lands where desirable, and improving the efficiency of the present market structure.

Time is a vital factor in forest production, and actions taken now will produce results only in the distant future. If intensification of forest land use begins immediately, the present regional harvest of timber can be maintained. If intensification is long postponed the current deterioration of the forests will continue until annual harvests have to be reduced in order to build up the forests again. General eco-

nomic welfare will be highest if the program to intensify forest land use is expanded immediately.

In general, the attainment of the economic optimum intensity of forest land use will have desirable social results in the Region. The necessary changes in forest land use will, however, involve some social problems. Steps must be taken to solve these problems simultaneously with the changes in forest land use; the social maladjustments may otherwise cancel out the increase in general welfare which results from economic improvement.

Conclusions

The purpose of this study has been to investigate the potentialities of a concept: optimum intensity of forest land use on a regional basis. The device we have used is the analysis of forest land use under real conditions in an actual study region—a portion of the Georgia Piedmont. We have carried this sample analysis through to the point where we can specify an optimum intensity of forest land use for the study region and see its implications for the general economic welfare. What conclusions can we draw from this study about the general usefulness of the concept of optimum intensity of forest land use?

In the first place we have a rather clear picture of what this concept of optimum intensity of forest land use involves. By using forest land we can obtain certain benefits which we would not get if we left the land alone. But in order to obtain these benefits, we must apply to the land some amount of the other productive factors—labor and capital. We could use these same factors in some other form of production and thus obtain other benefits. If these other benefits added more to our total satisfaction than those we obtain by using the forest land, we would be better off to leave the forest land alone and engage in the other form of production.

We can vary our use of forest land by applying different amounts of the other productive factors to it. "Intensity" of use is an expression of the quantity of other factors combined with a unit of land in the productive process. There is a whole scale of possible intensities of use for any unit of forest land, each producing a different amount of benefits. That intensity which adds most to total economic welfare is the optimum. Neither the total benefit produced nor the net benefit above the cost of the factors used is a satisfactory measure of the comparative contribution to welfare. For this purpose we must use the relative benefit, i.e., the benefit produced for each unit of factor employed.

There is more, however, to determining optimum intensity than comparing the relative benefits produced by using various amounts of capital and labor. The same amount of these factors will produce different results if applied to the land in different ways. If our use is to be optimum, we must use a given amount of productive factors in the way which yields the maximum benefit. We cannot compare intensities of forest land use unless at each intensity we combine the productive factors in the most efficient technological manner. Efficient silviculture is the technical foundation of forest land use, and improvements in silvicultural techniques may change the intensity which is optimum.

Furthermore, forest land is a flow resource, and its services can continue over time without being exhausted. The services which the forest land will provide in the future, however, depend on how that land is used now. Some particular intensity of use may produce large immediate benefits but at the same time virtually eliminate future benefits. Another intensity may yield smaller immediate benefits, but these may continue indefinitely in undiminished amount. The optimum intensity is that which produces maximum relative benefits over all time. This raises the problem of totaling or comparing benefits which occur at different points in time. Time preference exists, even from the viewpoint of

society as a whole, and although we may "place the future very nearly on a par with the present" (Hutchison, 1951), we must value present benefits higher than equivalent future benefits in our comparisons (Vaux, 1951). The exact interest rate at which we discount future benefits in allowing for this social time preference is probably not too important, as it is unquestionably low and could vary only within a narrow range.

Since forest land is a flow resource, its services are lost unless they are used. An acre of forest land is capable of producing a certain amount of wood per year, but this productive potential must be used each year; it cannot be accumulated by not being used. If we use land in such a way as to produce only half its potential yield one year, we cannot make this up by producing one-and-a-half times the potential in some future year. So optimum intensity of forest land use is also a minimum. If forest land is managed at an intensity below the optimum, production which would have added to economic welfare does not take place and total economic welfare is less than it might have been.

On a regional basis, intensity of forest land use involves the combination of other productive factors with all of the forest land in the region. Since the forest land in any region varies in quality, we may combine the other factors with it in various patterns. We cannot express intensity of use on a regional basis in terms of the total quantity of other factors applied to the land in the region. We cannot even express it meaningfully as an average of the amount of other factors applied per acre. The only real expression of regional intensity of use is a schedule of the classes of forest land in the region and the intensity of use applied to each class. Rather than a single optimum intensity of forest land use for the region, we must have a schedule of optima for the various classes of land in the region. The optimum intensity of use for any one land class will depend as much on the relative efficiencies of the other land classes and the amount of them present in the region as on its own size and productive efficiency.

We can now attempt to condense all of this into a definition. Optimum intensity of forest land use on a regional basis is that pattern of quantities of labor and capital, applied through efficient silviculture to the production of forest products on the different classes of forest land in the region, which will make a greater contribution to total economic welfare over time than could any other use of the quantities of all the productive factors involved. The use of more or less of the other factors, or their combination with the land in any other pattern, would result in a smaller contribution to total economic welfare.

From this definition we can see that the determination of optimum intensity of forest land use on a regional basis is a complex problem involving many variables. The first set of variables consists of the characteristics of the forest land resource itself. Three main classes of characteristics affect its use: (1) the productive capacity of the land, including the various products which it can produce; (2) the present condition of the forest stand on the land; and (3) the ownership status of the land, including the size of individual properties. The productive capacity controls the total amount of any and all products which can be produced in a region. It also largely determines the cost of producing them. The present condition of the forest and the ownership status have a major influence on the cost of realizing the productive potential of the land. Wide variations in all three of these characteristics are found in any region. The amount of land in their various classes is extremely important because this defines the forest resources of the region and sets limits to its use.

The second important variable affecting land use is the demand for the products which that land might produce. Regardless of what the land can produce, demand will

control the use to which it is put. This demand is reflected in the prices for which various products can be sold. The market structure available to the region also has an important influence on prices and thus on forest land use.

The regional problem is to make the best use of a given forest land resource under given conditions of demand for forest products. Here is where technology enters the picture. Silviculture and forest management are variables which we must adjust in such a way as to achieve the most efficient production of specified products with our given land resources. But we cannot make this adjustment without considering still other variables. Labor and capital are necessary for the practice of silviculture and the management of forest land. The cost of these factors and their supply, especially the supply of technical labor, influence the silviculture and management which we can carry out.

The nature of forest production, particularly because of the time element, is such that our competitive economic system does not seem to bring about the necessary adjustments. So we must consider as another variable the administration of programs to promote and develop the needed adjustments in forest land use. This brings political and social considerations into the picture. Determining the intensity of forest land use is primarily an economic problem, but political and social variables will influence the economic variables.

The number of variables which affect forest land use makes it almost impossible for efficiency to be attained automatically. Yet we need efficient forest land use if we hope to maximize general welfare. Guidance and control of forest land use is essential in the public interest, and the conservation programs now active in this country show that we have long recognized this. The decisions about this guidance and control must be in the hands of policy–making groups which can see forest land use in its proper setting as one of the many factors affecting public welfare. If such groups are to make wise decisions, they need a clear understanding of the potentialities and implications of forest land use adjustments. The concept of an optimum intensity of forest land use can help them get such understanding. This sets up an ideal which probably cannot be attained in practice but which does provide a goal toward which actions can be directed. Analyses of optimum intensity can make clear the existence and the interrelationships of the variables which affect forest land use, as we have shown in this study. Such analyses should be invaluable to policy–makers in forming the decisions for which they are responsible.

Literature Cited

CRAFTS, E. C. 1955. Timber resources for America's future. Chap. I, Timber Resource Review (prelim. draft), U.S.D.A. For. Serv. 129 pp.

CRUIKSHANK, J. W. 1947. 1946 pulpwood production by county in the Southeast. Southeast. For. Exp. Sta. For. Surv. Rel. 23. 18 pp.

————, and W. C. ANDERSON. 1955. Pine sawtimber stumpage prices in South Carolina, 1948-1954. Southeast. For. Exp. Sta. Sta. Pap. No. 57. 14 pp.

FLOYD, D. L., and H. A. WHITE. 1949. Average prices paid Georgia timber producers for standing timber and sawlogs (as of September 15, 1949). Ga. Crop Rep. Serv. 2 pp.

————. 1952. Average prices paid Georgia timber producers for standing timber and sawlogs (as of September 15, 1952). Ga. Crop Rep. Serv. 2 pp.

HUTCHISON, S. B. 1951. A yardstick for judging public forestry projects. J. For. 49: 99-101.

JAMES, L. M., W. P. HOFFMAN, and M. A. PAYNE. 1951. Private forest landownership and management in Central Mississippi. Miss. St. Coll. Agric. Exp. Sta. Tech. Bull. 33. 38 pp.

McCormack, J. F. 1948. 1946 commodity drain by county from South Carolina forests. Southeast. For. Exp. Sta. For. Surv. Rel. 26. 25 pp.

———, and J. W. Cruikshank. 1954. Forest statistics for Georgia, 1951-53. Southeast. For. Exp. Sta. For. Surv. Rel. 44. 77 pp.

Office of Forest Experiment Stations and Cooperating Agencies. 1929. Volume, yield and stand tables for second-growth southern pines. U. S. Dept. Agric. Misc. Pub. 50. 202 pp.

Rettie, J. C. 1955. Future domestic requirements for timber. Chap. VI, Timber Resource Review (prelim. draft), U. S. Dept. Agric., For. Serv. 141 pp.

Schnur, G. L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. U. S. Dept. Agric. Tech. Bull. 560. 87 pp.

Stanford Research Institute. 1954. America's demand for wood. Stanford Res. Inst., Stanford, Cal. 404 pp.

Stover, W. S., and J. F. Christopher. 1955. 1954 pulpwood production in the South. South. For. Exp. Sta. For. Surv. Rel. 76. 13 pp.

Thomson, R. B. 1942. An examination of basic principles of comparative forest valuation. Duke Univ. Sch. of For. Bull. 6. 99 pp.

Todd, A. S., Jr. 1955. Pulpwood from small sawmill and logging residues: problems and opportunities. J. For. 53: 416-419.

U. S. Bureau of the Census. 1948. Lumber production in Georgia: 1946. U. S. Dept. Comm. Facts for Industry. 61 pp.

———. 1952. Census of agriculture: 1950. Counties and state economic areas. Georgia. Vol. 1, Part 17. 392 pp.

U. S. Forest Service. 1946. Potential requirements for timber products in the United States. Rept. 2 from A Reappraisal of the Forest Situation. U. S. Dept. Agric. For. Serv. 70 pp.

Vaux, H. J. 1951. Comments on "A yardstick for judging public forestry projects." Jour. For. 49: 101-103.

Worrell, A. C. 1953. Costs of practicing forestry in the South. Univ. Ga. Sch. For. Leaflet 13. 5 pp.

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Material such as equations that exceed 42 spaces on the typewriter cannot be carried in a single line. Such material should either be set so that it can be broken into two or more lines, or should be presented in tabular form.

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Footnotes used in tables should be designated by numerals, never by asterisks or other typographical symbols. These footnotes should be typewritten as part of the table.

Illustrations and Figures

An illustration — whether a photograph, a line drawing, a map, or a graph — is designated as a figure. A caption should be submitted for each illustration, but the caption should be typewritten on a separate sheet.

All figures should be numbered consecutively. If only one is submitted it should be designated Figure 1. On the margin or back of each illustration should be written lightly in soft pencil the number of the figure, the name of the author, and an abbreviated title.

Photographs should be sharp and clear, printed on glossy paper. They should not be smaller than 4 by 5 inches. Sizes 5 by 7 inches and 8 by 10 inches are preferable. Photographs should never be rolled or bent. Care should be taken in fastening photographs with paper clips which often make indentations that show up in reproduction.

Drawings, maps, charts, and graphs are reproduced as line engravings. They should be at least twice as large as they are to appear when reproduced, and should be drawn in india ink on heavy white paper, or tracing cloth.

Footnotes

To indicate a footnote, place a superior figure after the word that refers to the note. Consecutive numerals should be used, never asterisks. Separate the footnote from the text by running a line about one inch inward from the left margin of the type.

Use footnotes to give credit to unpublished material and communications. If only a few references to literature are made (less than one per 1000 words), complete literature citations may be given in footnotes rather than in a separate listing.

Literature Cited

In Forest Science practice, references to literature citations are designated by the author's name and year of publication inserted in parentheses at the appropriate place in the text. If there are more than two authors, list only the senior author's name in the text with the abbreviation *et al.* Example: (Smith *et al.*, 1954). Only published references should be given in *Literature Cited*. Periodical abbreviations should follow *Guide to the use of Forestry Abstracts*, Commonwealth Forestry Bureau, Oxford, England, 1950.

Nomenclature and Terminology

When a species is first mentioned in a paper its common name may be immediately followed by its italicized scientific name in parentheses, but this latter name need not be repeated.

As the authority for the exact spelling of tree names, Forest Science follows *Check List of Native and Naturalized Trees of the United States (including Alaska)*, Agriculture Handbook 41, Forest Service, U. S. Dept. Agric., Washington, D. C., 1953.

For the spelling of other plant names, contributors should follow *Standardized Plant Names*, 2d Edition, J. Horace McFarland Company, Harrisburg, Pa. 1942.

Technical usage in forestry and allied fields follows *Forestry Terminology*, 2d Edition, Society of American Foresters, Washington 6, D. C. 1950.

There are many style manuals available for the guidance of writers. One of the best is the *Style Manual* of the U. S. Government Printing Office, Washington 25, D. C. 1953.

Webster's *New International Dictionary* is the accepted authority for general spelling.